PB-217 239

WATER SUPPLY AND WATER QUALITY CONTROL STUDY NAVASOTA RIVER WATERSHED LOWER BRAZOS RIVER SYSTEM, TEXAS. STUDY OF NEEDS AND VALUE OF STORAGE FOR MUNICIPAL AND INDUSTRIAL WATER SUPPLY AND WATER QUALITY CONTROL

Public Health Service
Dallas, Texas

June 1965

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WATER SUPPLY AND WATER QUALITY CONTROL STUDY NAVASOTA RIVER WATERSHED LOWER BRAZOS RIVER SYSTEM TEXAS

Study of Needs and Value of Storage for Municipal and Industrial Water Supply and Water Quality Control

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Public Health Service, Region VII
Dallas, Texas

JUNE 1965

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WATER SUPPLY

AND

WATER QUALITY CONTROL STUDY

NAVASOTA RIVER WATERSHED

LOWER BRAZOS RIVER SYSTEM

TEXAS

Abstract

An investigation has been carried out which discloses the need for and value of storage for municipal and industrial purposes in the proposed Millican and Navasota II Reservoirs on the Navasota River. A portion of the future needs for water in the study area can be satisfied from storage in these projects. The investigation further found that there is no need for storage for water quality control in the proposed reservoirs. Economic and demographic studies revealed a potential for increased industrial development and population growth, and serve as the foundation for the projected needs.

Prepared for

DEPARTMENT OF THE ARMY

U.S. Army Engineer District

Fort Worth, Texas

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service, Region VII
Dallas, Texas

JUNE 1965

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I. INTRODUCTION

Request and Authority

In a letter dated June 8, 1959, the Corps of Engineers, Fort Worth District, requested ". . .Views and recommendations of Health, Education, and Welfare on present and prospective needs for municipal and industrial water supply for Bryan, Navasota, and College Station, also industrial and irrigation water for consumers in the lower Brazos valley and desirability of meeting these needs from a reservoir project on the Navasota River. . . ." In compliance with this request, a report entitled "Municipal and Industrial Water Requirements, Millican Reservoir, Navasota River, Lower Brazos River System, Texas" was prepared and submitted in July 1960. Since the preparation of this report, there have been several changes in (1) the laws governing water resources planning; (2) the planning policies of Federal agencies; and (3) the plans for the reservoir projects included in the original request.

The U.S. Army Engineer District, Fort Worth, in a letter dated February 17, 1964, requested a restudy of the Navasota River ". . .to determine for a 100-year period the municipal and industrial water requirements, the quality of water, the extent of existing and potential pollution, as well as the need for and the benefits from conservation storage for purposes of municipal and industrial water supply and water quality control. . . ."

This study has been made in accordance with: (1) A Memorandum of Agreement between the Department of the Army and the Department of Health, Education, and Welfare, dated November 4, 1958; and (2) The Federal Water Pollution Control Act, as amended (33 USC 466 et seq.).

Purpose and Scope

The purpose of this study is to estimate the water requirements for municipal, industrial, and water quality control purposes to the year 2075 in the lower Brazos River basin, which includes the Navasota River watershed. Estimates are made of the value of benefits attributable to the storage of water for these purposes in the Federally proposed Navasota River reservoir projects.

Acknowledgments

The cooperation of many persons and agencies is gratefully acknowledged. Special appreciation is expressed to the following:

U.S. Army Engineer District, Fort Worth, Texas
U.S. Geological Survey, Austin, Texas

Texas State Department of Health, Austin, Texas
Texas Water Commission, Austin, Texas
Brazos River Authority, Waco, Texas
Bryan-College Station Chamber of Commerce, Bryan, Texas
Officials of cities in the study area

II. SUMMARY OF FINDINGS AND CONCLUSIONS

Summary of Findings

1. The U.S. Army Engineer District, Fort Worth, is considering the development of the Navasota River watershed through the construction of multiple-purpose reservoirs. Generally these plans utilize three main stem reservoir sites: Millican at river mile 24.05; Ferguson at mile 41.46; and Navasota Site II at mile 83.36.

2. The study area comprises 21 counties in south-central Texas, enclosing an area with boundaries generally coincident with the lower Brazos River basin, as shown on figure III-1.

3. These 21 counties had a total population of about 789,000 in 1960. Of this total, 474,000 were classified as urban, and 315,000 as rural.

4. Except for the Standard Metropolitan Statistical Areas (SMSA's) of Waco and Galveston-Texas City, the area is generally rural in character. Rapid urbanization is taking place, however, in such cities as Mexia, Temple, Bryan-College Station, Richmond, and Freeport whose present population exceeds 10,000.

5. The study area is in a period of rapid economic expansion. Waco has a highly diversified manufacturing complex, and growth of the petrochemical industry in the Freeport and Galveston-Texas City areas is extremely dynamic.

6. Present municipal and industrial water use in the study area is about 340 million gallons per day (mgd), with surface water sources supplying almost 255 mgd and ground water contributing about 85 mgd. Eighty-three percent (280 mgd) of this use is centered in the gulf coast counties. In addition, the chemical industry along the gulf coast uses about 2,500 mgd of brackish water for cooling.

7. The major water-using industries in the study area are chemicals and allied products, and food and kindred products. Other major uses are irrigation and recreation.

8. The aggregate storage of the existing and under construction major reservoirs is 1,657,370 acre-feet. Reported ground water pumpage in 1958 amounted to more than 250,000 acre-feet.

9. Current inventories show that there are 83 municipal and industrial waste treatment plants in operation in the study area. In general, these plants provide secondary treatment and are operating efficiently.

10. The organic quality of the waters of the lower Brazos River basin as measured by dissolved oxygen can be described as good. (The dissolved oxygen concentration does not drop below 4.0 milligrams per liter (mg/1).)

11. The mineral quality of the Brazos River main stem, downstream from Whitney Reservoir, is poor. The weighted average total dissolved solids concentrations vary from 415 mg/1 near the mouth to 1,240 mg/1 at Waco, Texas. This condition is due primarily to extensive natural brine pollution in the upper Brazos River basin.

12. The water quality of the proposed project reservoirs is acceptable for municipal, industrial, recreational, fish and wildlife, and agricultural uses.

13. This study, comprising the lower Brazos River basin, and its findings will be included in the pending investigation of the entire Brazos River basin by the Public Health Service.

Conclusions

1. To insure continued growth, careful planning for efficient development of all of the study area's water resources is essential.

2. The study area's population is expected to reach 2,040,000 by the year 2025, and 3,401,000 by the year 2075. The urban segment of these totals is 1,878,000 and 3,267,000 in 2025 and 2075, respectively. Similarly, the rural portion of the population is expected to be 162,000 in 2025, and 134,000 in 2075.

3. Estimated future municipal, industrial, and rural water supply needs for the lower Brazos River basin, including the assigned intervening coastal area, are 1,326 million gallons per day (mgd) in the year 2025 and 2,088 mgd in the year 2075.

4. With the water supply plan as presented herein, the potential water resources of the lower Brazos River basin are sufficient to satisfy municipal, industrial, and rural water requirements until about the year 2028. It is assumed that the projected irrigation needs to this time will also be satisfied.

5. The future organic quality of lower Brazos River basin waters is expected to remain satisfactory for municipal, industrial, recreational, fish and wildlife, and agricultural uses.

6. Present undesirable concentrations of total dissolved solids in the main stem of the Brazos River downstream from Whitney Reservoir can be expected until natural brine pollution of the upper basin is controlled. Current studies being made by the Corps of Engineers and the Public Health Service indicate that adequate control of the brine emission areas may be possible.

7. Municipal and industrial water supply releases from the project reservoirs (Millican and Navasota II) will reduce concentrations of total dissolved solids under stated drought conditions to some extent in the Brazos River below the mouth of the Navasota River even if none of the natural brine pollution of the upper basin is controlled. This incidental reduction, however, is not considered sufficient to create significant benefits to water users in the lower Brazos basin.

8. Storage in Millican and Navasota II Reservoirs will satisfy a portion of the future municipal and industrial water requirements in the study area. The need for storage for water quality control purposes is not foreseen at this time.

9. Minimum annual values of benefits of storage for water supply based on the cost of the most likely alternative (single-purpose impoundments at the project site) are as follows:

Reservoir	Annual Water Supply Benefits
Millican	$1,418,000
Navasota II	914,000

III. PROJECT DESCRIPTION

General

The Navasota River is a principal tributary of the lower Brazos River in east-central Texas. Originating in the southeast corner of Hill County, the river flows southeastwardly across Limestone County, where it begins a southerly course forming the eastern boundaries of Robertson and Brazos Counties to its confluence with the Brazos River at mile 233, near Navasota, Texas. The Navasota River drainage area comprises 2,211 square miles, having a length of 122 miles and a maximum width of 35 miles.

The watershed includes portions of Hill, Limestone, Robertson, Leon, Brazos, Madison, and Grimes Counties, and lies within the West Gulf Coastal Plain section of the Coastal Plain physiographic province. The watershed changes gradually from typical prairie topography and vegetation in the north portion to the relatively hilly and forested characteristics of the East Texas Timber Belt in the south portion. Elevations in the watershed vary from about 650 feet near the headwater divide, to about 185 feet near its mouth. The boundaries of the watershed are shown in figure III-1 at the back of this report.

Pertinent Project Data

There are several development plans for the Navasota River under consideration by the Corps of Engineers. These plans generally include some combination of the Millican and Navasota Site II or Ferguson Reservoir sites. The conservation storage for municipal and industrial water supply of these plans varies from 566,200 acre-feet to 2,462,200 acre-feet. Similarly, the dependable yields vary from 150 mgd to 310 mgd.

The locations of the reservoir sites are shown in figure III-1, and more specific pertinent data for a number of the plans being considered are shown in table III-1.

Table III-1

Pertinent Data
Navasota River Reservoir Projects

Reservoir and Plan	River Mile	Conservation Storage (acre-feet)	Dependable Yield (mgd)
Millican	24.05		
Plan A		680,200	194
Plan B		1,410,400	246
Plan C		2,408,300	310
Ferguson	41.46		
Plan A		566,200	162
Plan B		1,243,400	210
Plan C		1,835,700	248
Navasota Site II	83.36		
Plan A		678,700	150
Plan B		1,206,800	187
Plan C		1,574,100	210
Millican & Navasota Site II System			
Plan A (Navasota No. II as first project)	(See above)	2,462,200	304
Plan B (Millican as the first project)		2,460,000	307

Source: Corps of Engineers 1/

IV. STUDY AREA DESCRIPTION

Location and Boundaries

The study area comprises 21 counties enclosing an area with boundaries generally coincident with the lower Brazos River basin. (See figure III-1 at the back of this report.) This study and its findings will be included in the pending investigation of the entire Brazos River basin by the Public Health Service.

Although this study is primarily concerned with water resource development in the Navasota River watershed (see preceding section on PROJECT DESCRIPTION), this study area was chosen so as to include the entire area which might be served by the water resources of the lower Brazos River basin utilizing a single integrated plan of development. This plan utilizes ground water resources in the entire area, as well as surface water resources of the entire lower Brazos River basin.

Geography and Topography

The Brazos River flows in a general southeasterly direction through the study area to the Gulf of Mexico. The slope of the riverbed varies from approximately 1.2 feet per mile near Waco to less than 0.5 feet per mile near the gulf. [27]

The terrain changes from rolling hills in the northern portion of the study area to a flat coastal plain in the southern section. The table-like topography of the alluvial plain along the main channel of the Brazos River does not afford economical reservoir sites.

Climate

The lower Brazos area is characterized by a mild and fairly uniform climate. The mean annual temperature varies from about 70° in the coastal area to 66° in the vicinity of Waco. From Waco to the gulf coast, the normal annual rainfall varies from 33 inches to 47 inches. The average length of the growing season ranges from 260 days in the northern portion to 320 days near the coast.

Principal Communities and Industries

The study area was divided into four subareas for the purpose of providing suitable size base areas for study and at the same time maintaining a reasonable degree of homogeneity of economic, water resource, and geographic factors. The principal characteristics of each of the subareas are shown in table IV-1. The boundaries of the subareas are shown on figure III-1.

Table IV-1

Characteristics of the Subareas

Sub-area	Counties	Principal Cities	1960 Population (1,000's)	Population Class	Economy	Topography	Altitude (feet)	Mean Annual Temp. (°F)	Growing Season (days)	Average Rainfall (inches)
1	Falls, Hill McLennan	Marlin, Hillsboro, Waco	195	Metropolitan	Industrial, Commercial, Agriculture, Livestock	Level to Rolling	300-900	66	241	35.7
2	Brazos, Grimes, Leon, Limestone, Madison, Robertson	Bryan, College Station, Navasota, Centerville Maxia, Madisonville, Hearne	111	Non-Metropolitan	Agriculture, Livestock, Industrial, Commercial	Level to Rolling	150-600	66	248	38.8
3	Bell, Burleson, Burnet, Lee, Milam, Williamson	Temple, Caldwell, Burnet, Giddings, Cameron, Rockdale, Taylor, Georgetown	181	Non-Metropolitan	Agriculture, Livestock, Industrial, Mining	Hilly to rolling	225-1600	67	257	34.1
4	Austin, Brazoria, Fort Bend, Galveston, Waller, Washington	Bellville, Freeport, Angleton, Richmond, Sugarland, Galveston, Texas City, Hempstead, Brenham	302	Metropolitan	Industrial, Agriculture, Mining, Shipping	Coastal plain to rolling	0-500	69	285	43.1

Source: A. H. Belo Corporation 4/

V. WATER RESOURCES OF THE STUDY AREA

Ground Water

Principal aquifers in the basin are the Trinity group; the Carrizo sand and Wilcox formation, undifferentiated; the Miocene sands (Catahoula sandstone, Oakville sandstone, and Lagarto clay, undifferentiated); the Coastal sands (Goliad sand, Willis sand, and Lissie formation and Beaumont clay); and the Quaternary alluvium in the West Gulf Coastal Plain. Figure V-1 shows the general location of these aquifers in the basin.

Secondary aquifers include the Trinity group in the Central Texas section and the Mount Selman formation, Sparta sand, and Yegua formation in the West Gulf Coastal Plain. Several additional aquifers yield small quantities of water to individual areas in the basin.

Quantity of Water Available

Present ground water withdrawal in the lower Brazos River basin and the intervening coastal area* is 223.7 mgd, with over one-half of this total used in Subarea 4. Table V-1 presents 1958 ground water usage by subareas.

Table V-1

Base Year Ground Water Withdrawal
Lower Brazos River Basin and Intervening Coastal Area

Subarea	1958 Ground Water Withdrawal (mgd)
1	16.0
2	42.5
3	27.6
4	137.6
TOTAL	223.7

Source: University of Texas 3/
Texas Board of Water Engineers 4/

*This is a coastal drainage area which has been assigned to the Brazos River basin for water supply planning purposes in previous statewide planning reports. See figure III-1.

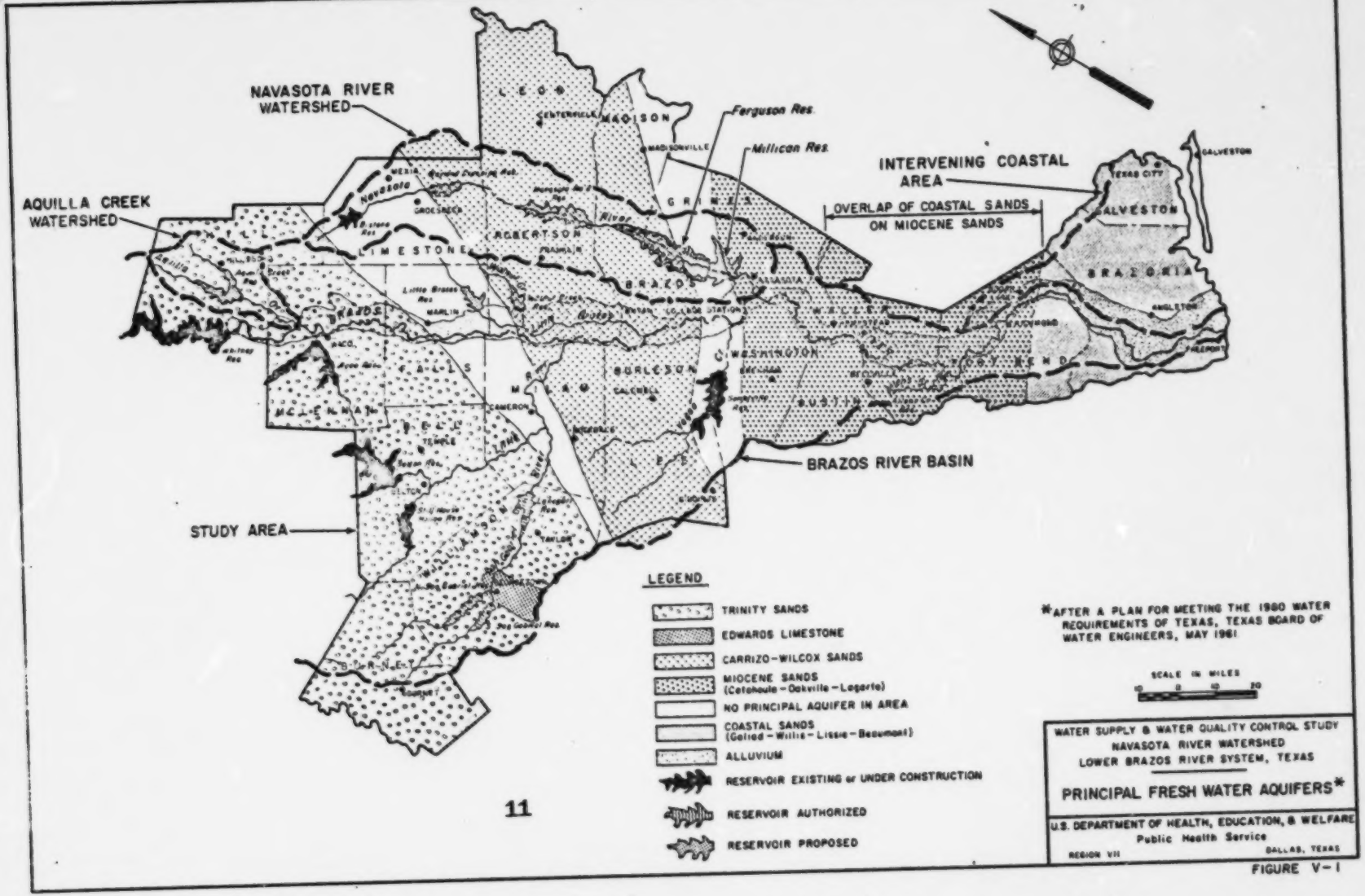

NAVASOTA RIVER WATERSHED
AQUILLA CREEK WATERSHED
STUDY AREA
INTERVENING COASTAL AREA
OVERLAP OF COASTAL SANDS ON MIOCENE SANDS
BRAZOS RIVER BASIN
Ferguson Res.
Millican Res.
LEON
MADISON
GRIMES
ROBERTSON
LIMESTONE
BRAZOS
FALLS
MCLENNAN
BELL
CORYELL
BURLESON
WASHINGTON
LEE
AUSTIN
WHARTON
BRAZORIA
GALVESTON
TEXAS CITY
LEGEND
TRINITY SANDS
EDWARDS LIMESTONE
CARRIZO-WILCOX SANDS
MIOCENE SANDS (Catahoula - Oakville - Lagarto)
NO PRINCIPAL AQUIFER IN AREA
COASTAL SANDS (Goliad - Willis - Lissie - Beaumont)
ALLUVIUM
RESERVOIR EXISTING or UNDER CONSTRUCTION
RESERVOIR AUTHORIZED
RESERVOIR PROPOSED
*AFTER A PLAN FOR MEETING THE 1980 WATER REQUIREMENTS OF TEXAS, TEXAS BOARD OF WATER ENGINEERS, MAY 1961
SCALE IN MILES
10 0 10 20
WATER SUPPLY & WATER QUALITY CONTROL STUDY
NAVASOTA RIVER WATERSHED
LOWER BRAZOS RIVER SYSTEM, TEXAS
PRINCIPAL FRESH WATER AQUIFERS*
U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
Public Health Service
REGION VII
DALLAS, TEXAS

FIGURE V-1

The ground water that is potentially available for municipal and industrial, thermal power generation, irrigation, and rural use throughout the lower Brazos River basin and intervening coastal area was evaluated as 450.9 mgd. Approximately 65 percent of this total is located in Waller, Fort Bend, Brazoria, and Galveston Counties in Subarea 4. Table V-2 shows the distribution of the available ground water by subareas.

Table V-2

Ground Water Availability
Lower Brazos River Basin and Intervening Coastal Area

Subarea	Ground Water Availability (mgd)
1	25.1
2	86.2
3	25.7
4	313.9
TOTAL	450.9

Source: Texas Water Commission 5 6/

Quality of Water Available

The chemical quality of ground water differs throughout each aquifer as well as in different aquifers. Analysis of the water from selected wells in the principal aquifers in the basin is given in table V-3. The extreme and the mean were evaluated from only a portion of the total number of analyses on record, but they were considered as representative of the quality of the water in the aquifer. Because of the difficulty in differentiating the Miocene sands and the Coastal sands, these aquifers were studied as a unit. In general, the chemical quality of ground water in the principal aquifers is such that with proper treatment the water is acceptable for municipal and industrial water supply purposes.

The public water supplies of many communities are obtained from the Trinity sands, although the concentrations of dissolved solids, iron, and fluoride in many of the wells exceed the recommended upper limits of the U.S. Public Health Service. The water is suitable for most types of industries, but high concentrations of sodium bicarbonate may be undesirable in boiler and laundry operations. Generally, the Trinity sands yield water that is suitable for irrigation.

The quality of water in the northwestern part of the Carrizo and Wilcox sands formation 6/ is acceptable for municipal use.

Table V-3

Characteristic Analysis of Ground Water from the Principal Aquifers in the Lower Brazos River Basin and Intervening Coastal Area

Characteristic	Trinity Sands a/ Concentration (mg/l)			Carrizo-Wilcox Sands b/ Concentration (mg/l)			Miocene and Coastal Sands c/ Concentration (mg/l)			Alluvium d/ Concentration (mg/l)		
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
Silica (SiO_2)	24	13	20	25	16	20	29	15	21	23	16	18
Iron (Fe)	0.94	0.01	0.23	11	0.02	2	0.37	0.08	0.19	*	*	*
Calcium (Ca)	270	2.8	48	121	2.4	26	74	22	44	440	56	171
Magnesium (Mg)	42	0.8	9	37	0.5	7	18	6.1	11	136	5	50
Sodium & Potassium (Na & K)	1420	213	540	656	45	217	188	89	129	384	15	164
Bicarbonate (HCO_3)	492	209	384	714	78	417	367	253	308	828	276	509
Sulfate (SO_4)	3320	75	690	186	0	37	118	0.2	31	570	17	182
Chloride (Cl)	628	50	206	620	19	128	305	43	106	880	16	290
Fluoride (F)	3.6	0.8	2.1	0.7	0.1	0.4	0.6	0.2	0.4	0.5	0.1	0.3
Nitrate (NO_3)	1.2	0	0.4	2.0	0	0.6	2.5	0	0.5	76	0	21
Dissolved Solids	5370	594	1731	1650	247	649	792	300	499	2790	407	1234
Hardness (as $CaCO_3$)	846	10	158	454	8	93	258	80	155	1630	227	637
Percent Sodium	98	78	86	99	19	72	*	*	*	40	22	31
Specific Conductance (micromhos @ 25°C)	3300	988	2018	2880	441	1340	1430	516	858	4300	825	1935
pH (pH units)	8.2	7.3	8.0	8.5	6.2	7.7	8.2	7.0	7.5	7.7	6.7	7.1

a/ Data from 8 wells
b/ Data from 9 wells
c/ Data from 6 wells
d/ Data from 13 wells

* Data not available

Source: Texas Water Commission 6/

Concentrations of iron in excess of 0.3 milligrams per liter (mg/l), the upper limit established for drinking water by the U.S. Public Health Service, exist in some locations and treatment is desirable. The water is suitable for many industrial needs or can be made suitable with nominal treatment. Water from the northwestern half of the aquifer is suitable for at least supplemental irrigation. 6/

Most of the water in the Catahoula sandstone, Oakville sandstone, and Lagarto clay, undifferentiated, and the Goliad sand, Willis sand, and Lissie formation, undifferentiated, is moderately hard to very hard, although soft water can be obtained in the central part of the region by selectively screening wells in the 1,000 to 2,500 foot depth zone. 6/ The water is generally suitable for public supplies and most industrial purposes. Water from these formations that is being used for irrigation would be classified as low to medium for the alkali hazard and medium to high for the salinity hazard.

The quality of the water from wells in the alluvium along the Brazos River varies greatly, as shown by the following range of concentrations; dissolved solids, 407 to 2,790 mg/l, hardness, 227 to 1,630 mg/l, chloride, 16 to 890 mg/l, specific conductance, 825 to 4,300 micromhos per centimeter. No public water supplies are obtained from the alluvium below the Navasota River.

Table V-4 shows the range and mean values of chemical constituents of the ground water from municipal wells in the Navasota River watershed. These concentrations are within the limits set by the U.S. Public Health Service with the exception of total dissolved solids (TDS). The maximum value of 637 mg/l TDS was in the supply of the city of Navasota, the only community to exceed 500 mg/l.

Table V-4

Characteristic Analysis of Water from Municipal Wells in the Navasota River Watershed

Item	Concentration (mg/l) Max.	Min.	Avg.
Iron (Fe)	0.25	0.04	0.12
Calcium (Ca)	35	2	14
Magnesium (Mg)	10	1	3
Sodium (Na)	220	23	111
Sulfate (SO_4)	29	1	15
Chloride (Cl)	83	13	43
Fluoride (F)	0.5	0.2	0.3
Nitrate (NO_3)	1.3	0.4	0.6
Total Hardness (as $CaCO_3$)	128	5	52
Total Dissolved Solids (Residue at 105°C)	637	125	335
pH (in pH units)	8.3	6.3	7.6

Source: Texas State Department of Health [7 8]

Surface Water

Quantity of Water Available

In the lower Brazos River basin, there are 6 reservoirs either existing or under construction which have a total dependable yield of 566.6 mgd or 634,650 acre-feet per year. [1] These are Whitney, Belton, Waco, Stillhouse Hollow, Somerville, and Bistone. In addition, North San Gabriel, South San Gabriel, and Laneport are authorized projects which will yield 52.4 mgd. Construction of proposed reservoirs will increase the total yield of the studied basin to 1,140.8 mgd in 2025 and 1,163.1 mgd in 2075. Table V-5 lists the individual reservoir yields.

Table V-5

Reservoir Yields
Lower Brazos River Basin

Reservoir		Dependable Yield (mgd)
Existing or under construction		
Whitney		304.0
Belton		104.7
Waco		54.9
Stillhouse Hollow		63.3
Somerville		36.2
Bistone		3.5
	SUBTOTAL	566.6
Authorized		
North San Gabriel		19.4
Laneport		22.0
South San Gabriel		11.0
	SUBTOTAL	52.4
Proposed		
Millican		193.9
Aquilla Creek		9.7
Long Range		
Navasota II (incremental yield)		113.1
Walnut Creek		19.4
Allens Creek		185.7
Wayland Crossing (to be constructed after 2025)		13.6
Little Brazos River (to be constructed after 2025)		8.7
	SUBTOTAL	544.1
	TOTAL	1,163.1

Source: Corps of Engineers 1/

The runoff for the uncontrolled drainage area between Whitney Reservoir and the mouth of the Brazos River, which is circumscribed by Whitney, Aquilla Creek, Waco, Belton, Stillhouse Hollow, Laneport, Little Brazos, Walnut Creek, Somerville, Millican, and Allens

Creek Reservoirs, was estimated. A discharge-frequency curve was constructed from runoff data of this area for a 31-year period of record. 9-11/ The runoff value from this curve, based on a 98 percent recurrence interval, is 202.5 mgd.

Quality of Water Available

The estimated dissolved solids concentrations of the principal reservoirs in the lower Brazos River basin are shown in table V-6. The concentrations were estimated applying the relationship of the quantity of runoff and total dissolved solids concentration for the drainage area of the study reservoir. Using reservoir operation data furnished by the Corps of Engineers, periodic concentrations in the reservoir were determined. In this manner, a total dissolved solids frequency curve was developed and the total dissolved solids concentration of each reservoir was evaluated based on annual low flows.

Table V-6

Estimated Total
Dissolved Solids Concentration in Principal
Reservoirs in the Lower Brazos River Basin

Reservoir	Total Dissolved Solids Concentration (mg/l) Exceedence Interval		
	50%	80%	98%
Whitney	870	870	870
Aquilla Creek	412	610	795
Waco	255	263	350
Belton	372	428	645
Stillhouse Hollow	410	489	608
Laneport	413	498	668
Somerville	262	370	635
Millican[a/]	172	237	330

a/Assuming correction of oil field pollution in the Navasota River upstream from the reservoir.

The quality of Brazos River waters is unsatisfactory upstream of Possum Kingdom Reservoir* because of natural salt and gypsum

*This reservoir is located on the Brazos River at mile 687.5, which is about 245 river miles upstream of Whitney Reservoir. It is not shown on the Location Map, figure III-1.

pollution, but improves as it flows downstream by dilution from better quality tributary waters. The best recorded quality occurs more than 800 miles downstream from the origin of the river, or some 93 miles from the Gulf of Mexico. Weighted average concentrations of total dissolved solids, chlorides, and sulfates of 20 streamflow sampling stations located in the lower Brazos River basin are shown in table V-7.

As will be noted in Section VIII, the natural mineral pollution of the upper Brazos River basin greatly overshadows all other basin pollution. This pollution consists primarily of chlorides, from natural brine emission areas, and sulfates, picked up by upper basin streams whose drainage areas and beds contain large areas of exposed gypsum. It has been estimated that this area contributes a daily load of 995 tons of chlorides, 12/ 687 tons of sulfates, 12/ and 3,073 tons of total dissolved solids. 12/

The Corps of Engineers and the Public Health Service are currently conducting studies of methods to eliminate or reduce discharges from sources of mineral pollution. If this mineral load can be kept from entering basin waters, the water quality of the entire Brazos River will be greatly improved.

Table V-7

Characteristic Analysis of Streamflow in the Lower Brazos River Basin

Location of Sampling Station	Samples	Weighted Average Concentration (mg/l) Total Dissolved Solids	Sulfates	Chlorides
Brazos River at Whitney Dam near Whitney	a/	851	175	260
Aquilla Creek at FM Road 1244 near Elm Mott	1	849	325	82
Brazos River at Waco	1	1,240	325	450
Brazos River near Marlin	33	808 b/	204	296
Leon River near Belton	1	272	28	27
Leon River at Bridge on U.S. Highway 81 near Belton	1	505	58	102
Leon River near Temple	3	474	52	96
Nolands Creek at Belton	1	464	56	86
Lampasas River at Fort Hood	4	516	19	188
Lampasas River at U.S. Highway 81 near Belton	1	290	13	73
North San Gabriel River at Georgetown	1	364	22	18
South San Gabriel River at Georgetown	1	311	25	18
San Gabriel River at Georgetown	2	292	26	21
Brushy Creek at Round Rock	1	292	20	15
Little River at Cameron	c/	295	32	30
Brazos River near Bryan	37	853 d/	186	263
Yegua Creek near Somerville	1	803	272	168
Navasota River near Bryan	e/	206	26	71
Navasota River near Navasota	1	435	55	140
Brazos River at Richmond	f/	415	76	101

a/ Continuous sampling from September 9, 1947 through May 16, 1948, and from October 1948 through September 1961.

b/ 31 Samples

c/ Continuous sampling from October 1959 through September 1961.

d/ 35 Samples

e/ Continuous sampling from October 1958 through September 1961.

f/ Continuous sampling from October 1945 through September 1961.

VI. THE ECONOMY

Present

Determination of future water requirements for the study area envolves appraisal of the area's population and industrial growth potential. Estimation of future growth patterns of the study area, therefore, are made by (1) a comparison of past trends between the study area, the State of Texas, and the United States on three basic measures: income, employment, and population, and (2) a detailed analysis of specific economic activity of agriculture, mining, and manufacturing with special emphasis given to those industries which will have the greatest effect on future water requirements of the study area.

Income

As shown in table VI-1, per capita disposable income in the study area is increasing at a faster rate than that of Texas or the United States. In 1960, per capita disposable income was lower for the study area than for Texas or the Nation.

Table VI-1

Per Capita Disposable Income
for the Study Area, Texas, and U.S., 1940 and 1960
(1960 dollars)

Year	Study Area		Texas		U.S.	
	Value	% Change	Value	% Change	Value	% Change
1940	739	+100	936	+85	1,274	+52
1960	1,476		1,729		1,937	

Source: Corps of Engineers 1/

Employment

The total labor force in the study area increased 9 percent between 1940 and 1960 compared to a 48 percent increase for Texas and a 32 percent increase for the Nation. This increase was achieved in spite of a loss of 60,000 agricultural workers between 1940 and 1960. As shown in table VI-2, agriculture still employs a larger portion of the labor force in the study area than in Texas or the United States.

Table VI-2

Labor Force and Employment for the Study Area, Texas, and the United States
1940, 1950, 1960

	1940				1950				1960			
	No. of Employees Study Area	Percent of Total Labor Force Study Area	Texas	U.S.	No. of Employees Study Area	Percent of Total Labor Force Study Area	Texas	U.S.	No. of Employees Study Area	Percent of Total Labor Force Study Area	Texas	U.S.
Agriculture, Forestry, and Fisheries	96,081	38.1	26.0	16.1	59,342	23.3	15.0	11.7	36,125	13.2	8.0	6.2
Mining	3,455	1.4	2.5	1.7	3,879	1.5	3.0	1.5	3,108	1.1	2.8	.9
Manufacturing	13,657	5.4	8.6	20.0	27,393	10.7	12.6	24.3	39,504	14.4	14.9	25.1
Chemicals & Allied	719	.2	.4	.8	6,275	2.5	1.0	1.1	11,022	4.0	1.3	1.2
Other Nondurables	2,173	.9	1.9	3.2	4,442	1.7	2.3	2.7	6,350	2.3	2.3	2.5
Food and Kindred	3,124	1.2	1.7	2.1	4,044	1.6	2.0	2.3	5,148	1.9	2.2	2.6
Furniture, Lumber & Wood Products	1,927	.8	1.4	1.7	2,620	1.0	1.5	2.0	3,279	1.2	.9	1.5
Other Manufacturing	5,714	2.3	3.2	12.2	10,012	3.9	5.8	16.2	13,705	5.0	8.2	17.3
Service & Other Employed	108,443	42.9	50.0	47.7	154,801	60.7	65.6	57.8	182,550	66.6	70.0	62.8
Unemployed 1/	30,747	12.2	12.9	14.5	9,805	3.8	3.8	4.7	12,809	4.7	4.3	5.0
Total Labor Force	252,383	100.0	100.0	100.0	255,220	100.0	100.0	100.0	274,096	100.0	100.0	100.0

1/ 1940 includes those employed on public emergency works.

Source: Bureau of the Census 13/

Population

The study area is fairly heavily populated, with 44.8 persons per square mile compared to 36.5 and 60.1 for Texas and the continental United States, respectively. (See table VI-3.) Two SMSA's (Waco and Galveston-Texas City), located at upper and lower extremities of the study area, accounted for more than one-third of the 1960 study area population. The study area contains 9 cities with 1960 populations in excess of 10,000. These 9 cities have a total population of 315,370 or 40 percent of the 1960 study area population. The study area in 1960 had a higher percentage of rural residents than Texas or the Nation. The overall study area population trend since 1910 has been predominately upward with total population increasing 35 percent during this time. The study area urban population grew at a compounded annual rate of 3 percent between 1930 and 1960 while Texas and the Nation urban population grew at 3.7 and 2.0 percent, respectively.

Specific Economic Activity

Agriculture

Total value of all farm products sold increased 84 percent in the study area between 1944 and 1959 compared to a 76 percent for the State of Texas and a 54 percent increase for the United States. (See table VI-4.) The sale of livestock and livestock products was the cause of most of this increase. In 1959 livestock sales accounted for more than 50 percent of the total value of farm products sold. The study area has diversified livestock programs with sales resulting from beef, poultry, hogs, dairy, broilers, sheep, and goats. Cotton is the leading income-producing crop grown in the study area. Annual production of cotton averages over 300,000 bales valued at approximately 10 million dollars. Most of the cotton produced in the study area is ginned in the 187 gins located in the study area. 2/ Irrigated rice is important in the gulf coast region of the study area. Other crops grown include: corn, grain sorghums, oats, peanuts, figs, and truck crops. With 13 percent of the 1960 study area labor force employed in agriculture, farming remains one of the mainstays of the economy. In Texas, 8 percent of the 1960 labor force was employed in agriculture, while 6 percent of the Nation's labor force was employed in agriculture. The study area has continued to increase its output while losing more than 60 percent of its workers between 1940 and 1960.

Table VI-3

Population--Urban and Rural, and Population Per Square Mile for the Study Area, Texas, and the United States, 1910-1960

	Year	Total Population (1,000)	Percent Urban	Percent Rural	Population Per Sq. Mi.
Study Area	1910	587	N/A	N/A	33.4
	1920	619	24.5	75.5	35.2
	1930	671	28.6	71.4	38.1
	1940	670	32.7	67.3	38.1
	1950	715	47.8	52.2	40.6
	1960	789	60.1	39.9	44.8
Texas	1910	3,897	24.1	75.9	14.8
	1920	4,663	32.4	67.6	17.8
	1930	5,825	41.0	59.0	22.1
	1940	6,415	45.4	54.6	24.3
	1950	7,711	62.7	37.3	29.3
	1960	9,580	75.0	25.0	36.5
United States	1910	91,972	45.7	54.3	30.9
	1920	105,711	51.2	48.8	35.5
	1930	122,775	56.2	43.8	41.2
	1940	131,669	56.5	43.5	44.2
	1950	150,697	64.0	36.0	50.7
	1960	179,323	69.9	30.1	60.1

Source: Bureau of the Census [14/]

Table VI-4

Agricultural Statistics for the Study Area Compared to Texas and the United States 1944, 1949, 1954, 1959

	1944	1949	1954	1959	Percent Change 1944-1959 Study Area	Texas	U.S.
Number of Farms	53,439	64,481	42,395	32,722	-39	- 41	-38
Acres of Cropland Harvested (1,000)	2,621	2,722	2,567	2,114	-19	- 19	- 3
Acres Irrigated	83,798	140,277	165,932	136,755	+63	+328	+62
Value of Crops Sold 1/	52,010	103,990	91,183	89,609	+72	+ 81	+59
Value of Livestock Sold 1/	48,786	52,022	58,287	95,828	+96	+ 71	+51
Total Value of Farm Products Sold 1/	100,796	156,012	149,470	185,437	+84	+ 76	+54

1/ Values in 1,000's of 1960 dollars.

Source: Bureau of the Census 15/

Mining

The study area's mineral production was valued at 285 million dollars in 1961. The bulk of minerals produced occurred in the gulf coast region of the study area. Brazoria County ranked first in natural gas production and third in total value of minerals produced in the State. Sizable quantities of the minerals extracted are processed by the numerous refineries, chemical and petrochemical installations in the area. A total of 38 million barrels of crude oil were produced in the study area in 1960. 2/ Sulphur is presently being commercially extracted from salt domes on the Texas gulf coast. However, between 1952 and 1961 extraction of sulphur from these sources declined more than 20 percent because of increased competition from other sources of sulphur including domestic and foreign frasch sulphur and domestic sulphur recovered from sour gas. 16/ Large lignite deposits in Milam County are strip-mined and used as a source of power for the aluminum plant at Rockdale.

Manufacturing

In 1960, 39,500 workers were employed in manufacturing in the study area. They accounted for 14.4 percent of the total labor force compared to 14.9 for Texas and 25.1 for the Nation. As shown in table VI-5, a study area value added by manufacturing was 638 million dollars in 1958. This value was 13 percent of the State total. Value added per worker in the study area was $17,527, while value added per worker in Texas was $10,854.

Table VI-5

Manufacturing Data for the Study Area
1939, 1947, 1954, 1959

	1939	1947	1954	1958
Number of Establishments	--	453	541	610
Number of Employees	--	24,471	32,855	36,403
Value Added by Manufacturing 1/ (1,000 1960 Dollars)	66,245	209,063	457,487	638,034
Value Added Per Worker	--	8,543	13,924	17,527

1/ Values estimated for counties where data was withheld to avoid disclosing figures for individual companies.

Source: Bureau of the Census 17/

Chemical production is the largest single manufacturing industry in Texas, as measured in annual net value of products. Chemical production had a net annual worth of more than a billion

dollars in 1958. It is the newest, most rapidly growing large Texas industry. It is the leading Texas industry in capital expenditures per employee. By 1961 an estimated 3.7 billion dollars had been invested in gulf coast chemical plants. 2/ As shown in table VI-2, 11,000 workers were employed by the chemical industry in the study area in 1960. These workers accounted for 27 percent in the manufacturing employment, compared to 9 and 5 percent respectively for Texas and the Nation. Study area employment in the chemical industry has increased 15-fold since 1940. Over 90 percent of those employed in the production of chemicals were located in Galveston and Brazoria Counties.

The gulf coast region also has numerous petroleum refineries, the largest being located in Texas City. The employment category, other nondurable goods (see table VI-2), contains those employed in petroleum refining. The rubber tire factory in Waco, which employes over 1,000 people, is also included in this category. Petroleum refining and rubber products account for most of those employed in other nondurable goods. Employment in other nondurable goods tripled between 1940 and 1960.

Over 5,000 workers were employed by the food and kindred processing industry in 1960. The larges of these food processors in the study area is the sugarcane refinery located at Sugarland in Fort Bend County. Other food processing includes a brewery, meat processing, canneries, and food processing normally associated with urban areas such as bakeries, dairies, etc.

Other significant manufacturing includes: aluminum reduction, magnesium reduction, tin and tungsten smelting, ship building, furniture and fixtures, apparel, printing and publishing, leather, stone, clay, and glass products.

As described in Chapter IV, the study area was divided into four major subareas to facilitate determination of water requirements to be satisfied from the Navasota River watershed. Significant economic data for each subarea are shown in table VI-6.

Table VI-6

Changes of Major Economic Indicators for Subareas for Period Shown

	Subarea 1	2	3	4
Disposable Per Capita Personal Income (1960 Dollars)				
1940	806	585	618	891
1960	1,537	1,180	1,357	1,617
% Change	+91	+102	+120	+81
Population				
Total 1920	162,470	136,534	167,818	152,035
1960	195,004	110,874	180,795	302,088
% Change	+20	-19	+8	+99
Urban 1920	52,867	17,590	29,265	51,830
1960	135,125	55,068	89,553	194,487
% Change	+156	+213	+206	+275
Value of Farm Products Sold (1,000 1960 Dollars)				
1944	24,442	17,673	32,143	29,348
1959	41,057	35,701	54,260	54,377
% Change	+68	+102	+69	+85
Value of Minerals Produced (1,000 1960 Dollars)				
1952	2,896	2,647	584	242,954
1961	4,621	6,527	6,387	261,832
% Change	+60	+147	+994	+8
Value Added by Manufacturing (1,000 1960 Dollars)				
1939	18,501	2,803	6,328	38,613
1958	94,401	10,792	41,805	491,037
% Change	+410	+285	+561	+1,172

Source: Corps of Engineers 1/, Bureau of the Census 14 15 17/
Bureau of Mines 16/

Future

Future economic growth of the Navasota River study area will be determined by the conditions of the national economy, the development of natural and human resources in the study area, and the development and protection of the water resources of the lower Brazos River basin.

The Nation's expected economic growth can best be expressed by indicators of income, employment, and population. Gross national product (GNP) is expected to exceed 5 trillion dollars by 2025, with per capita disposable income rising from less than $2,000 in 1960 to about $6,700 per capita by 2025. Present indications are that the total employment will be over 200,000,000 and the total population will reach nearly 550,000,000 by 2025. 18/ These indications reflect a thriving national economy in which the lower Brazos River basin will participate. Since the growth of the study area is expected to be closely related to national growth, the degree in which growth will occur in the study area will depend on its ability to compete with other regions of the United States in the production of goods and services.

In response to increasing regional and national demands for its products, agriculture in the study area is expected to increase its output. Continued emphasis on specialized crops and livestock programs will enable the study area to continue to increase its output while losing agricultural workers.

Oil and gas production in the study area is expected to continue to provide feed stocks for the expanding gulf coast refineries and petrochemical industries. Continuing production is possible with presently known reserves and secondary recovery by gas and water injection.

Manufacturing will be a major factor in the future growth of the study area. By 2025, manufacturing employment is expected to account for about 20 percent of the total labor force, which approaches the present proportion of manufacturing employment in industrial cities of the south-central States. This increased manufacturing activity will be a result of continued development of resource-oriented industries, as well as increased processing of imported products. Growth will also occur in market-oriented manufacturing to serve the increasing local and regional demands caused by continued growth of the study area and the rapidly expanding southwestern markets.

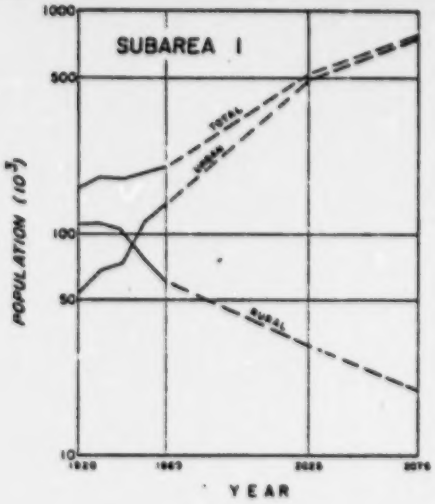
Significant growth in the petrochemical industry is expected in the study area. According to Resources for the Future's medium projection 19/, national requirements for petroleum based intermediates used in manufacturing of synthetics will increase 8-fold

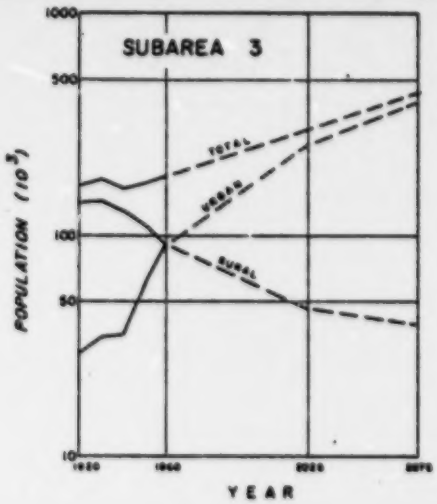
between 1960 and 2000. The study area has a definite advantage in the production of these intermediates with large amounts of petroleum and natural gas available to be used as inputs for the petrochemical process. The study area also has advantages of water transportation in import and export of products to be processed in the petrochemical industry. These factors, plus the fast growing southwestern market, indicate a high level of production for petrochemicals in the study area. Petrochemical employment is expected to more than double by 2025.

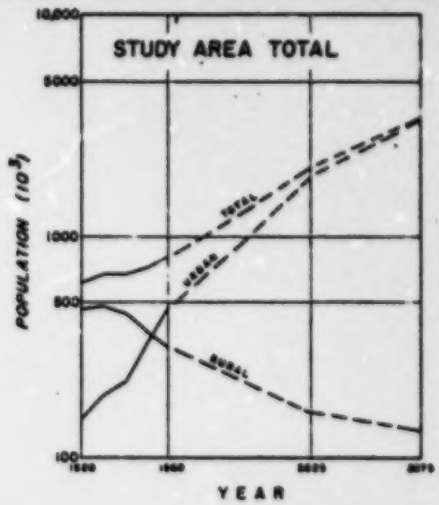
Food processing is projected to expand with industrialization and urbanization of the study area. Total employment in food and kindred processing is expected to reach approximately 23,000 by 2025. Most of this growth is expected to occur near the urban complexes in the upper and lower portions of the study area.

Significant increases of other manufactured products are expected. Much of these increases will be experienced in industries which regard market, transportation, and labor as the most important factors of production. Fabricated metals, machinery, transportation equipment, apparel, and other durable goods are examples of this type of manufacturing. Since many of these industries depend on imported materials, the gulf coast portion of the study area enjoys a competitive advantage to attract more of these manufacturers. The Galveston shipbuilding industry will form a nucleus for this type of growth.

To facilitate determination of municipal and industrial water requirements, employment and population projections were made for each of the 4 subareas shown in figure III-1. Employment projections to 2025 and 2075 for each subarea appear in table VI-7. Table VI-8 and figure VI-1 depict the anticipated population growth of the 4 subareas to 2075.







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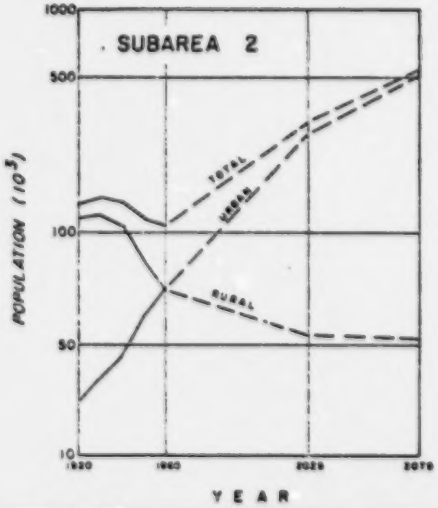
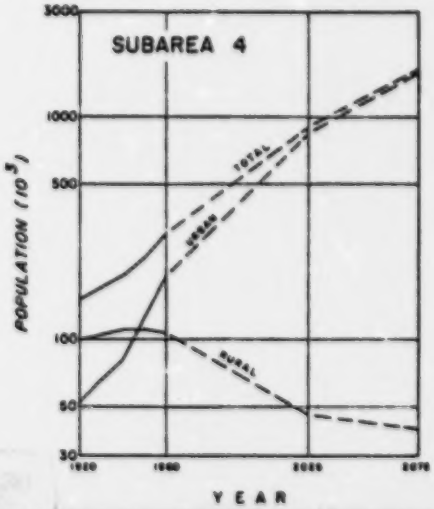




WATER SUPPLY & WATER QUALITY CONTROL STUDY
NAVASOTA RIVER WATERSHED
LOWER BRAZOS RIVER SYSTEM, TEXAS

POPULATION TRENDS AND PROJECTIONS

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
Public Health Service
REGION VII DALLAS, TEXAS

FIGURE VI-1

Table VI-7

Subarea Labor Force Projections
1960, 2025, 2075 (Part 1 of 4 - Subarea 1)

	1960		2025		2075	
	Number	Percent	Number	Percent	Number	Percent
Agriculture (Forestry & Fisheries)	7,541	10.6	2,800	1.4	2,800	.9
Mining, Total (SIC 13, 14)	76	.1	150	.1	250	.1
Manufacturing	11,243	15.8	32,450	16.7	52,350	17.5
Resource Oriented	6,983	9.8	19,200	9.9	29,700	9.9
Furn., Lbr., Wood (24, 25)	1,278	1.9	2,900	1.5	5,200	1.7
Pri. Metals (SIC 33)	12	-	250	.1	550	.2
Food & Kindred (SIC 20)	1,835	2.6	5,900	3.0	8,500	2.8
Chem. & Allied (SIC 28)	309	.4	700	.4	1,400	.5
Stone, Clay, Glass (SIC 32)	1,442	2.0	3,500	1.8	6,150	2.1
Other Nondurables (SIC 26, 29, 30, 31)	2,107	2.9	5,950	3.1	7,900	2.6
Nonresource Oriented	4,260	6.0	13,250	6.8	22,650	7.6
Fab. Metal (SIC 34, 35, 36, 37, 38)	1,329	1.9	5,700	2.9	9,400	3.1
Textiles (SIC 22, 23)	2,037	2.9	6,400	3.3	11,700	3.9
Print., Publ., NEC (SIC 27, 39)	894	1.2	1,150	.6	1,550	.6
Service and Other	48,745	68.6	151,360	77.8	232,600	77.5
Unemployed	3,474	4.9	7,740	4.0	12,000	4.0
TOTAL LABOR FORCE	71,079	100.0	194,500	100.0	300,000	100.0

Table VI-7

Subarea Labor Force Projections
1960, 2025, 2075 (Part 2 of 4 - Subarea 2)

	1960		2025		2075	
	Number	Percent	Number	Percent	Number	Percent
Agriculture (Forestry & Fisheries)	7,386	19.5	4,100	3.4	4,100	2.0
Mining, Total (SIC 13, 14)	241	.6	400	.3	650	.3
Manufacturing	2,648	7.0	34,600	28.6	58,700	28.5
Resource Oriented	1,830	4.8	28,000	23.1	47,000	22.8
Furn., Lbr., Wood (SIC 24, 25)	518	1.4	4,600	3.8	7,950	3.9
Pri. Metlas (SIC 33)	52	.1	4,300	3.6	7,000	3.4
Food & Kindred (SIC 20)	618	1.6	7,450	6.2	13,150	6.4
Chem. & Allied (SIC 28)	146	.4	3,700	3.0	5,600	2.7
Stone, Clay, Glass (SIC 32)	150	.4	1,300	1.0	2,300	1.1
Other Nondurables (SIC 26, 29, 30, 31)	346	.9	6,650	5.5	11,000	5.3
Nonresource Oriented	818	2.2	6,600	5.5	11,700	5.7
Fab. Metal (SIC 34, 35, 36, 37, 38)	203	.6	3,150	2.6	5,550	2.7
Textiles (SIC 22, 23)	370	1.0	1,500	1.2	2,800	1.4
Print., Publ., NEC (SIC 27, 39)	245	.6	1,950	1.7	3,350	1.6
Service and Other	25,819	68.1	77,100	63.7	134,300	65.2
Unemployed	1,837	4.8	4,800	4.0	8,250	4.0
TOTAL LABOR FORCE	37,931	100.0	121,000	100.0	206,000	100.0

Table VI-7

Subarea Labor Force Projections
1960, 2025, 2075 (Part 3 of 4 - Subarea 3)

	1960		2025		2075	
	Number	Percent	Number	Percent	Number	Percent
Agriculture (Forestry & Fisheries)	10,708	19.2	5,150	4.5	5,150	3.1
Mining, Total (SIC 13, 14)	550	1.0	1,050	.9	1,650	1.0
Manufacturing	5,412	9.7	18,050	15.9	32,250	19.5
Resource Oriented	3,939	7.1	13,700	12.0	24,450	14.8
Furn., Lbr., Wood (SIC 24, 25)	1,144	2.1	4,000	3.5	7,500	4.5
Pri. Metals (SIC 33)	915	1.6	2,800	2.4	4,950	3.0
Food and Kindred (SIC 20)	642	1.2	2,900	2.5	4,850	2.9
Chem. & Allied (SIC 28)	170	.3	450	.4	950	.6
Stone, Clay, Glass (SIC 32)	643	1.1	2,100	1.8	3,800	2.3
Other Nondurables (SIC 26, 29, 30, 31)	434	.8	1,450	1.4	2,400	1.5
Nonresource Oriented	1,473	2.6	4,350	3.9	7,800	4.7
Fab. Metal (SIC 34,35, 36, 37, 38)	559	1.0	2,050	1.8	3,500	2.1
Textiles (SIC 22, 23)	350	.6	1,450	1.4	2,900	1.8
Print., Publ., NEC (SIC 27, 39)	564	1.0	850	.7	1,400	.8
Service and Other	36,367	65.4	85,000	74.7	119,600	72.4
Unemployed	2,616	4.7	4,500	4.0	6,550	4.0
TOTAL LABOR FORCE	55,653	100.0	113,750	100.0	165,200	100.0

Table VI-7

Subarea Labor Force Projections
1960, 2025, 2075 (Part 4 of 4 - Subarea 4)

	1960		2025		2075	
	Number	Percent	Number	Percent	Number	Percent
Agriculture (Forestry & Fisheries)	10,490	9.6	6,600	2.0	6,600	1.0
Mining, Total (SIC 13, 14)	2,241	2.0	6,050	1.8	10,000	1.6
Manufacturing	20,201	18.5	77,550	22.9	118,800	18.6
Resource Oriented	16,935	15.5	54,350	16.0	75,550	11.8
Furn., Lbr., Wood (SIC 24, 25)	339	.3	1,050	.3	2,250	.4
Pri. Metals (SIC 33)	399	.4	6,000	1.8	11,600	1.8
Food & Kindred (SIC 20)	2,053	1.9	6,900	2.0	14,650	2.3
Chem. & Allied (SIC 28)	10,397	9.5	31,850	9.4	32,150	5.0
Stone, Clay, Glass (SIC 32)	284	.3	3,350	1.0	6,800	1.1
Other Nondurables (SIC 26, 29, 30, 31)	3,463	3.1	5,200	1.5	8,100	1.2
Nonresource Oriented	3,266	3.0	23,200	6.9	43,250	6.8
Fab. Metal (SIC 34, 35, 36, 37, 38)	2,269	2.1	17,250	5.1	32,500	5.1
Textiles (SIC 22, 23)	318	.3	4,200	1.3	8,800	1.4
Print., Publ., NEC (SIC 27, 39)	679	.6	1,750	.5	1,950	.3
Service and Other	71,619	65.4	234,700	69.3	476,350	74.8
Unemployed	4,882	4.5	13,550	4.0	25,550	4.0
TOTAL LABOR FORCE	109,433	100.0	338,450	100.0	637,300	100.0

Table VI-8

Subarea Population Projections
1960, 2025, 2075 (1,000's)

Subarea / Year	Urban	Rural	Total
I			
1960	135	60	195
2025	480	33	513
2075	751	20	771
II			
1960	55	56	111
2025	286	36	322
2075	510	34	544
III			
1960	90	91	181
2025	255	47	302
2075	395	40	435
IV			
1960	194	108	302
2025	857	46	903
2075	1,611	40	1,651
TOTAL			
1960	474	315	789
2025	1,878	162	2,040
2075	3,267	134	3,401

VII. WATER REQUIREMENTS

General

The term water requirements, as applied to an area the size of the lower Brazos River basin, encompasses several uses which are dependent upon a large number of variables. Although primarily concerned with water requirements for municipal, industrial, and water quality control purposes, this study examines all of the consumptive uses of water as they affect the supply and demand for water within the basin.

Types of Water Use

Municipal

Municipal water as defined here includes residential, commercial, public, and those industrial uses which can reasonably be reflected in a per capita use figure. Also included in the per capita quantities are losses in distribution systems and treatment plant attentuation.

Industrial

The definition of industrial water use in this study refers to all water except that supplied from municipal systems which is used by the manufacturing industries (Standard Industrial Classification Categories 13, 14, and 20 through 39). 20/

Power Generation

Use of water for thermal power generation is a part of the industrial requirement that has been determined separately. Although withdrawal for this purpose is very large, only the consumptive use is studied.

Rural

An estimate of the rural water use was made so as not to understate the total study area water requirements. As referred to in this investigation, rural water requirements are assumed to consist of domestic water for that portion of the population not served by municipal water systems and water for the maintenance of livestock.

Irrigation

Another important water use in the study area is irrigation. These requirements are included, since (1) return flows from this use affect the quality of the study area's water, and (2) a fully integrated water supply plan must include irrigation, especially in

an area where it represents a considerable portion of the demand on the potential water resource. Historic as well as projected quantities of water for this use were provided by the Corps of Engineers based on U.S. Study Commission-Texas values. [17]

Base Year Water Use

The year 1958 was selected as the base for the water use study because it was the most recent year for which reliable data from served sources were available. The 1958 study area water use by type is shown in table VII-1.

Table VII-1

Study Area Base Year Water Use

Subarea	1958 Water Use in MGD				
	Municipal	Industrial[a]	Rural	Irrigation	Total
1	19.4	3.8	6.0	6.0	35.2
2	10.9	1.5	5.6	39.1	57.1
3	14.9	5.9	9.1	12.2	42.1
4	29.9	252.1	10.8	269.7	562.5
Total Study Area	75.1	263.3	31.5	327.0	696.9

a/ Includes consumptive use for thermal power generation.

Source: Public Health Service [21], Texas Board of Water Engineers [4 22 23], University of Texas [3], and Census of Manufactures [24]

Similar estimates by basin and subbasins are shown in table VII-2.

Table VII-2

Basin and Subbasin Base Year Water Use

Basin	1958 Water Use in MGD				
	Municipal	Industrial[a]	Rural	Irrigation	Total
Lower Brazos*	53.2	123.2	22.4	190.2	389.0
Navasota	8.1	0.3	2.5	7.6	18.5
Aquilla Creek	1.6	Negligible	0.7	0.1	2.4
Intervening Coastal Area	18.9	115.7	3.3	118.8	256.7

a/ Includes consumptive use for thermal power generation.
* Includes the Navasota River and Aquilla Creek basins.

Future Water Requirements

Estimates of water requirements for the years 2025 and 2075 for the several types of water use (excluding irrigation) in the study area were made using the technique of combining projected unit uses with economic and population projections. Rural per capita use was assumed to remain constant from 2025 to 2075. Irrigation requirements were furnished by the Corps of Engineers based on U.S. Study Commission-Texas values. 1/

Municipal

The several items considered in making projections of per capita municipal water use for this study are as follows:

1. Past Trends - analysis of records from municipalities and industries.

2. Characteristics of the Subarea - factors peculiar to an area such as per capita income and precipitation.

3. Analysis of Projections by Others - projections made by other governmental agencies, consulting engineers, and the municipalities themselves.

4. Judgment - after considering and weighing the above factors, discrepancies which existed were resolved by judgment.

Present and projected values of per capita municipal use are shown in table VII-3.

Table VII-3

Municipal Per Capita Water Use
(in gal/day)

Subarea	1958	2025	2075
1	121	170	185
2	98	165	180
3	111	170	185
4	101	150	165

Industrial

Base year data on industrial water use were combined with employment data and resulted in a unit water use per employee for each of the industrial categories (Standard Industrial Classification 13,

14, and 20-39). Considerations involved in economic projections of the labor force required consolidation of some of the industrial categories into groups, as shown in table VII-4.

In order to project unit industrial water use, the following assumptions were made:

1. In presently undeveloped counties where large future developments are projected, the base year unit employee water uses were adjusted to those of surrounding counties where present conditions approach those forecasted for the undeveloped counties.

2. An average net productivity factor (i.e., the multiplier to obtain unit employee use for the years 2025 and 2075 from 1958 data) was determined as follows: Unit employee industrial water use projections of Resources for the Future, Inc., and the Business and Defense Services Administration prepared for the Senate Select Committee on National Water Resources [25] were extrapolated and an average curve constructed. The ratio of the 2025 and 2075 values to the 1958 value on the average curve gave the productivity factors of 2.1 and 2.6 for 2025 and 2075, respectively.

Special consideration was given to the water requirements for the chemical industry along the gulf coast. It was decided to determine a range of values based on the amount of in-plant recirculation. The amount of recirculation in this case is a function of the availability and cost of water. It seems reasonable to assume that as long as water is available at present prices, the recirculation practices will not be changed. This condition is represented by the high figures in table VII-4 and the upper curve of figure VII-1.

On the other hand, restrictions in the availability of water and increases in water costs will result in reduced requirements. These conditions are inducive to in-plant water conservation (recirculation and/or air cooling) and are dictated by the industry's economy. This condition is represented by the low figures in table VII-4 and the lower curve of figure VII-1.

It is expected that a transition from the high to low requirements will take place over a period of time as water availability and costs change. This transition is shown on figures VII-2, VII-3, and VII-6, and will be further discussed in Section IX of this report.

Unit industrial water use by subareas for all industries in the years 2025 and 2075 is shown in table VII-4.

In addition to fresh water, the chemical industry along the gulf coast uses about 2,500 mgd of brackish water for cooling.

Power Generation

Consumptive use of water for thermal power generation is considered to be a part of the industrial requirement but is determined separately. Information on future water use was gathered from power companies in the area and combined with data developed by the Federal Power Commission and the Edison Electric Institute for the Senate Select Committee on National Water Resources. Consideration was given to the general locations of future power generation installations and the projected needs apportioned throughout the study area using hypothetical service areas for the several generating plants.

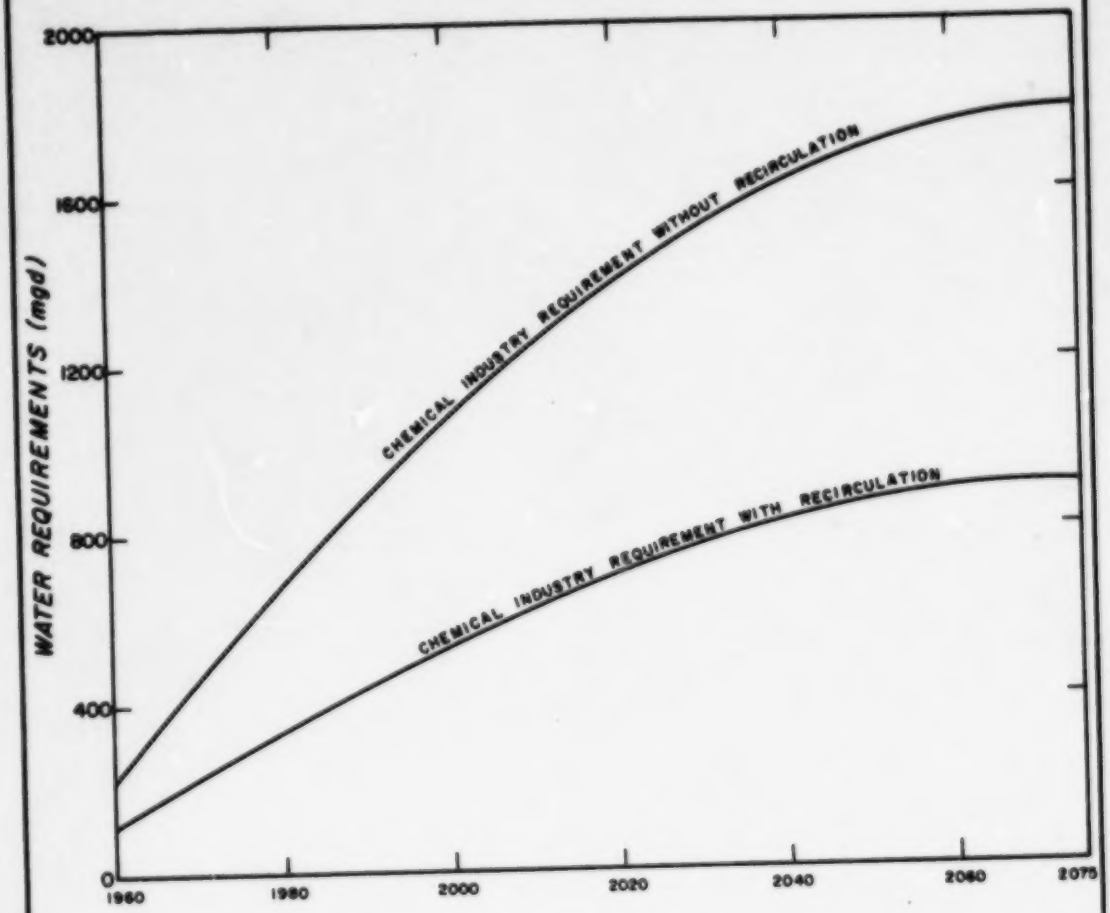
Rural

For purposes of this study, the rural water requirements are assumed to consist of domestic water for that portion of the population not served by municipal water systems and water for the maintenance of livestock. The 2025 and 2075 requirements for rural water are based on a rural per capita use of 180 gallons per day, of which 80 gpcd is for the maintenance of livestock.

The estimated future study area water requirements by subareas are shown in table VII-5.

Similar estimates of future water use for the basin and subbasins are shown in table VII-6.

Graphic illustrations of the water requirements for the study area, basin, and subbasins are shown in figures VII-2 through VII-6.

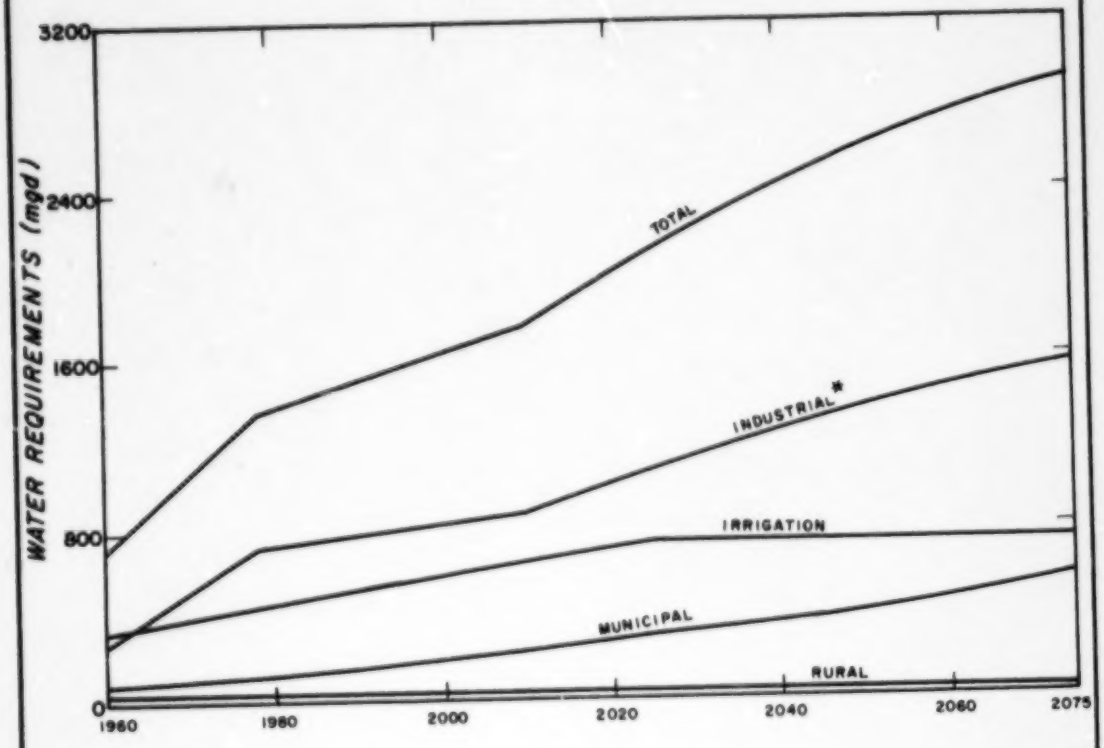


WATER SUPPLY & WATER QUALITY CONTROL STUDY
NAVASOTA RIVER WATERSHED
LOWER BRAZOS RIVER SYSTEM, TEXAS

CHEMICAL INDUSTRY WATER REQUIREMENTS
LOWER BRAZOS BASIN BELOW NAVASOTA RIVER (INCLUDES INTERVENING COASTAL AREA)

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
Public Health Service
REGION VII DALLAS, TEXAS

FIGURE VII-1



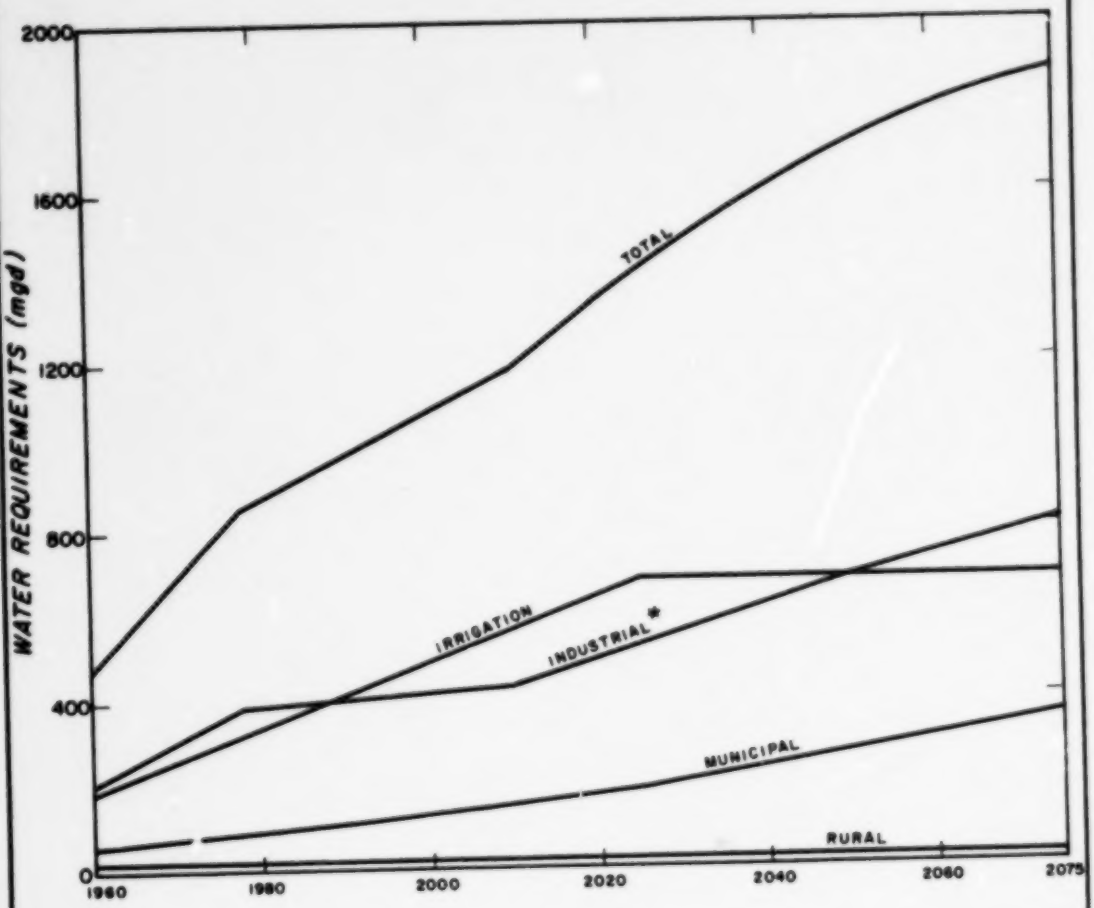
* INCLUDES CONSUMPTIVE USE FOR THERMAL POWER GENERATION

WATER SUPPLY & WATER QUALITY CONTROL STUDY
NAVASOTA RIVER WATERSHED
LOWER BRAZOS RIVER SYSTEM, TEXAS

STUDY AREA
WATER REQUIREMENTS

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
Public Health Service
REGION VII DALLAS, TEXAS

FIGURE VII-2



* INCLUDES CONSUMPTIVE USE FOR THERMAL POWER GENERATION

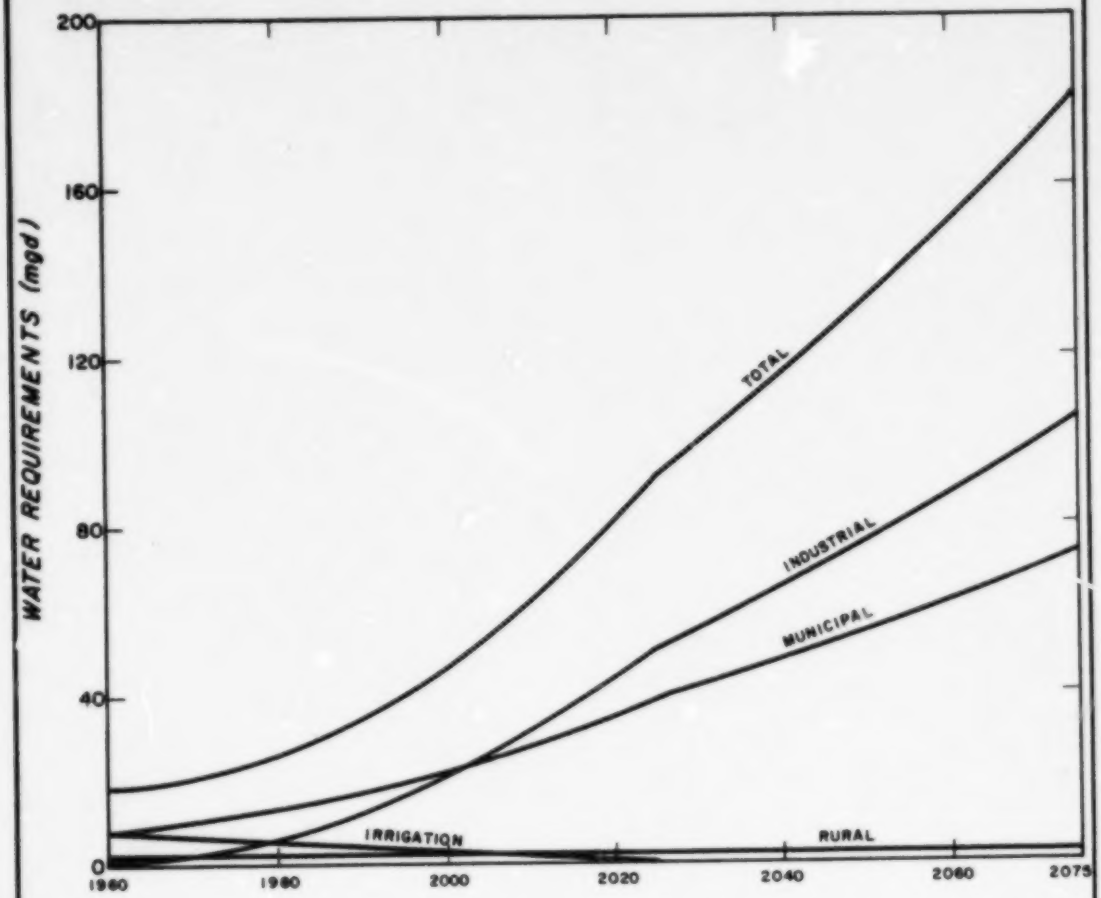
a/ INCLUDES NAVASOTA RIVER AND AQUILLA CREEK WATERSHEDS

WATER SUPPLY & WATER QUALITY CONTROL STUDY
NAVASOTA RIVER WATERSHED
LOWER BRAZOS RIVER SYSTEM, TEXAS

LOWER BRAZOS RIVER BASIN a/
WATER REQUIREMENTS

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
Public Health Service
REGION VII DALLAS, TEXAS

FIGURE VII-3

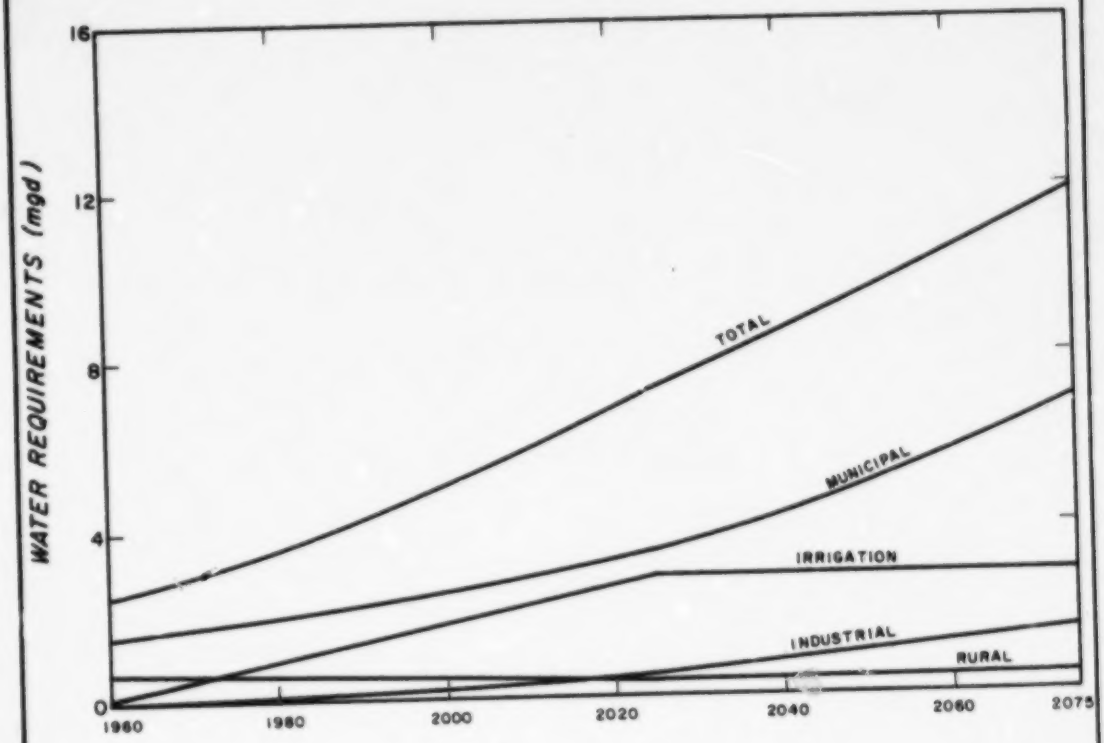


WATER SUPPLY & WATER QUALITY CONTROL STUDY
NAVASOTA RIVER WATERSHED
LOWER BRAZOS RIVER SYSTEM, TEXAS

NAVASOTA RIVER WATERSHED
WATER REQUIREMENTS

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
Public Health Service
REGION VII DALLAS, TEXAS

FIGURE VII-4

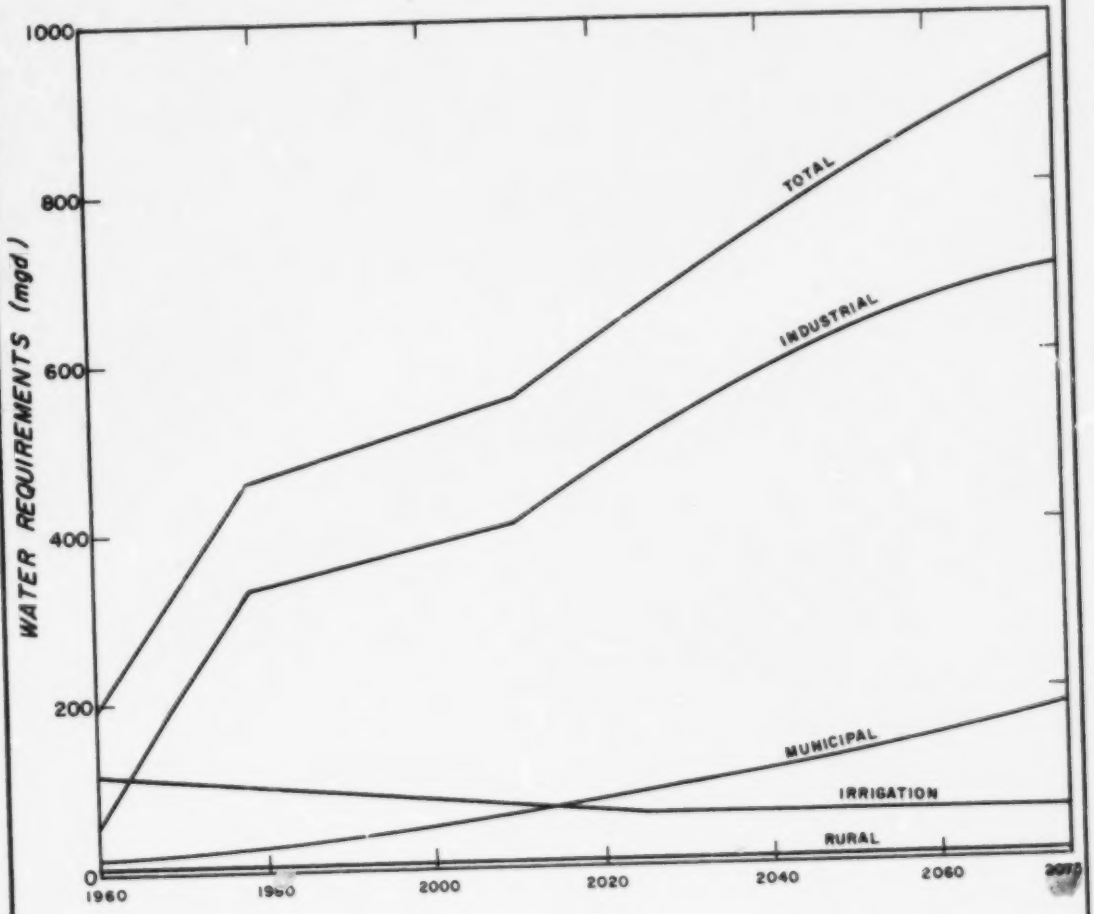


WATER SUPPLY & WATER QUALITY CONTROL STUDY
NAVASOTA RIVER WATERSHED
LOWER BRAZOS RIVER SYSTEM, TEXAS

AQUILLA CREEK WATERSHED
WATER REQUIREMENTS

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
Public Health Service
REGION VII DALLAS, TEXAS

FIGURE VII-5



WATER SUPPLY & WATER QUALITY CONTROL STUDY
NAVASOTA RIVER WATERSHED
LOWER BRAZOS RIVER SYSTEM, TEXAS

INTERVENING COASTAL AREA
WATER REQUIREMENTS

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
Public Health Service
REGION VII DALLAS, TEXAS

FIGURE VII-6

Table VII-4

Future Unit Industrial Water Use
(gal. per employee day)

Item	Subarea 1		Subarea 2		Subarea 3		Subarea 4	
	2025	2075	2025	2075	2025	2075	2025	2075
Mining (SIC 13, 14)	50	70	203	250	132	164	2,260	2,800
Manufacturing								
Furniture, Lumber & Wood(SIC 24, 25)	190	230	228	280	175	217	670	830
Primary Metals (SIC 33)	1,650	2,040	1,593	1,970	1,400	1,700	4,410	5,450
Food & Kindred (SIC 20)	450	560	1,446	1,790	530	660	2,680	3,320
Chemicals & Allied Products (SIC 28)	1,050	1,300	198	250	1,010	1,250	23,100-* 56,000	28,600- * 57,000
Stone, Clay, and Glass Products (SIC 32)	880	1,090	44,965	55,670	2,670	3,300	3,080	3,810
Petroleum (SIC 29)	530	660					10,400	12,880
Pulp and Paper (SIC 26)	210	280	491	610	500	620	5,250	6,500
Other Nondurables (SIC 30, 31)	510	630					320	390
Fabricated Metals (SIC 34, 35, 36, 37, 38)	170	210	163	200	150	186	210	270
Textile & Apparel (SIC 22, 23)	160	190	150	190	143	177	140	180
Printing & Publishing and Not Elsewhere Classified (SIC 27, 39)	40	50	40	50	40	50	40	50

* Exact value is dependent upon prevailing recirculation practices of the chemical industry on the gulf coast. See discussion on page VII-4.

Table VII-5

Future Study Area Water Requirements
(mgd)

Subarea	Municipal	Industrial*	Rural	Irrigation	Total
		For the Year 2025			
1	81.7	18.1	5.9	122.5	228.2
2	47.2	82.5	6.6	162.8	299.1
3	43.6	38.0	8.5	204.7	294.8
4	129.4	809.5 - 1614.4**	8.3	256.9	1204.1 - 2009.0**
TOTAL	301.9	948.1 - 1753.0**	29.3	746.9	2026.2 - 2831.1**
		For the Year 2075			
1	139.0	59.0	3.6	122.5	324.1
2	91.6	177.8	6.1	162.8	438.3
3	73.3	81.7	7.1	204.7	366.8
4	267.3	1247.5 - 2142.1**	7.2	256.9	1778.9 - 2673.5**
TOTAL	571.2	1566.0 - 2460.6**	24.0	746.9	2908.1 - 3802.7*

* Includes consumptive use for thermal power generation.
** Exact value is dependent upon prevailing recirculation practices of the chemical industry on the gulf coast. See discussion on page VII-4.

Table VII-6

Future Basin and Subbasin Water Requirements
(mgd)

Basin	Municipal	Industrial[a]	Rural	Irrigation	Total
		For the Year 2025			
Lower Brazos[b]	201.2	510.4 - 819.6[c]	21.4	685.4	1418.4 - 1727.6[c]
Navasota	38.5	50.1	2.5	0	91.1
Aquilla Creek	3.4	0.6	0.5	2.9	7.4
Intervening Coastal Area	87.6	503.1 - 915.3[c]	2.0	61.5	654.2 - 1066.4[c]

Municipal, industrial, and rural water requirements for the lower Brazos River basin, including the intervening coastal area, are 1,325.7 mgd in 2025.

		For the Year 2075			
Lower Brazos[b]	363.4	819.6 - 1203.0[c]	16.5	685.4	1884.9 - 2268.3[c]
Navasota	73.0	105.7	2.3	0	181.0
Aquilla Creek	7.0	1.6	0.5	2.9	12.0
Intervening Coastal Area	182.0	704.8 - 1215.9[c]	2.0	61.5	950.3 - 1461.4[c]

Municipal, industrial, and rural water requirements for the lower Brazos River basin, including the intervening coastal area, are 2,088.3 mgd in 2075.

[a] Includes consumptive use for thermal power generation.
[b] Includes the Navasota River and Aquilla Creek basins.
[c] Exact value is dependent upon prevailing recirculation practices of the chemical industry on the gulf coast. See discussion on page VII-4.

VIII. WATER QUALITY CONTROL

General

Water quality control is defined as any measure employed to enhance the utility, value, and attractiveness of waters used for purposes which are affected by changes in water quality. Waters in nature are never PURE in the strict chemical sense of the word. More often than not, however, natural waters are fit for use by man in his pursuit of normal endeavors. This use and subsequent return of waste almost always causes some degradation of water quality downstream, even after provision of secondary waste treatment. As population and the associated demand for water increase, this degradation of the water resource increases. Presently, water quality is controlled by providing the best available waste treatment. When further water quality improvement is needed, this treatment is supplemented by the provision of additional water to dilute the treated wastes. This, then, is the method of water quality control with which this report is concerned.

Municipal, Industrial, and Agricultural Pollution

Stream Loading

The determination of the quantity and quality of return flows expected to reach a stream is the first step necessary in analyzing water needs for quality control.

The quantity of municipal and industrial return flows is estimated as a percentage of water use. The municipal return flow percentages used vary from 34.5 percent to 76.0 percent, 26/ while industrial return flow percentages vary from 23 percent to 90 percent. 9/

The quality of municipal return flow is based on assumed per capita contributions of 0.23 pounds per day of total dissolved solids and 0.25 pounds per day of ultimate first-stage BOD.

The contribution of total dissolved solids resulting from industrial use varies from 1.2 tons per million gallons to 12.2 tons per million gallons of return flow. 9/ For the BOD contribution from industry, it was assumed that final industrial effluents which discharge wastes containing BOD would have the same concentration as a municipal sewage that has been treated to remove 85 percent of the BOD. This concentration is 56 mg/l ultimate first-stage BOD assuming a typical municipal sewage has an untreated concentration of 370 mg/l ultimate first-stage BOD.

It was assumed that there would be no return flow resulting from rural water use.

Irrigation return flows were assumed to be one-third of the water applied for that purpose, and it was further assumed that all of the dissolved solids in the irrigation source water would be returned to the stream. 27/

Present and projected municipal and industrial return flows, population equivalents, and total dissolved solids loads are shown in Appendix A of this report.

Water Quality Objectives

Of the indicators presently available as a measure of water quality, dissolved oxygen and total dissolved solids were chosen for use in this study. The principal causes of pollution in this river basin are (1) natural mineral pollution of the upper watershed which contributes a variety of chemical constituents that can best be described as total dissolved solids*; (2) domestic sewage and a large variety of industrial wastes, both of which contribute BOD and total dissolved solids; and (3) irrigation return flows. Water quality control requirements are based on the assumption that sufficient waste treatment will be provided for the manmade portion of the pollution to remove 85 percent of the BOD and none of the total dissolved solids.**

Water to regulate quality is assumed to be needed when the dissolved oxygen content of the stream drops below 4 mg/l# and/or when the total dissolved solids reach 1,000 mg/l.##

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* This source of pollution is much greater than all other pollution sources in the Brazos River basin and was previously discussed in Section V.

**With conventional treatment methods currently used, removal of some of the total dissolved solids probably occurs; however, this removal can be considered as incidental rather than planned and no reliable estimates of the quantity so removed are available.

The lower limit of 4 mg/l of dissolved oxygen was used since (1) it provides an acceptable environment for most aquatic life native to this area; and (2) it provides a buffer zone in the event unforeseen spills of waste occur.

##U.S. Public Health Service Drinking Water Standards 28/ restrict total dissolved solids concentration to 500 mg/l. A concentration of 1,000 mg/l, although it is not desirable, was used in this study because basin conditions make the limit of 500 mg/l unattainable. Further discussion of this situation appears in Sections V and VIII of this report.

Flow Regulation

Allowance for Streamflow

In determining the draft-on-storage required to preserve the quality of the stream, it is necessary to make allowances for natural flows that can be expected to occur in the stream. Discharge frequency analyses of the streams in the basin were made from Corps of Engineers' streamflow data, which included adjustments to reflect conditions in the basin in 2025. Calculations were then performed to determine the amount of regulation water from storage needed to maintain stream quality for hydrologic conditions that can be expected to recur in the basin streams every 50 years. This hydrologic condition was used since the downstream use of the water is for municipal and industrial purposes.

Quality Control Requirements

The analyses of the basin waters, one of organic pollution (BOD), and one of chemical pollution (total dissolved solids), were made utilizing electronic computational methods where applicable. These studies were made for the entire lower Brazos River basin by constructing a mathematical model of the basin containing all reservoirs and points of withdrawal and inflow to the system. Special emphasis was placed on conditions in the main stem of the Brazos at the point of confluence of the Navasota River. This approach was used, since this investigation is primarily concerned with water resource development in the Navasota River basin, and any benefits for water quality control attributable to this development would logically accrue downstream.

Computations of organic pollution indicated that the surface waters of the basin will not be degraded below acceptable limits within the time horizon of the study (2075).

On the other hand, concentration of the stable pollutants (total dissolved solids) in the stream below the confluence of the Navasota River will reach undesirable levels in the future. Since the amount of water required to lower these concentrations is dependent on the quality of water used for dilution, the amounts required and the provisions made for satisfying this need will be discussed in Section IX, Water Supply and Water Quality Control Plan.

An investigation was made to determine the effect of discharge of adequately treated sewage effluent from the cities of Bryan and College Station on the water quality in the proposed Millican Reservoir. 29/ (See Appendix C.) The quality of the water in Millican Reservoir is not expected to be adversely affected by these waste discharges.

IX. WATER SUPPLY AND WATER QUALITY CONTROL PLAN

General

In order to supply the water needs shown in Section VII, a plan is presented utilizing all available water resources in the lower Brazos River basin.

Water Availability

With existing and proposed reservoirs in operation, the water resources of the lower Brazos River basin (including the intervening coastal area) in the years 2025 and 2075 will be as shown in table IX-1.

An overplot of these resources on the total water requirement* for the basin and coastal area shows that the area's water resources will satisfy the total water requirements until about the year 2028, as shown in figure IX-1.

Closer examination reveals that the lower Brazos River basin above the confluence of the Navasota River and the Navasota River watershed have resources adequate to meet requirements through the terminal year of the study (2075). (See figures IX-2 and IX-3.) On the other hand, the Brazos basin below the confluence of the Navasota River and the associated intervening coastal area can be expected to become deficient by the year 2028, as shown in figure IX-4.

It should be noted that the greatest needs for water supply are now and can in the future be expected to be concentrated in the area downstream from the confluence of the Navasota River.

Water Quality Control Plan

The total requirement curves in figures IX-1 through IX-4 do not include any water quality control needs. There is, however, a need to control the total dissolved solids concentration in the Brazos River water downstream from the confluence of the Navasota River as was previously discussed in Sections VII and VIII.

A time plot of expected total dissolved solids concentrations in this reach of the stream under assumed hydrologic conditions is

*Calculated by addition of totals on figures VII-3 and VII-6. Totals do not include water quality control needs.

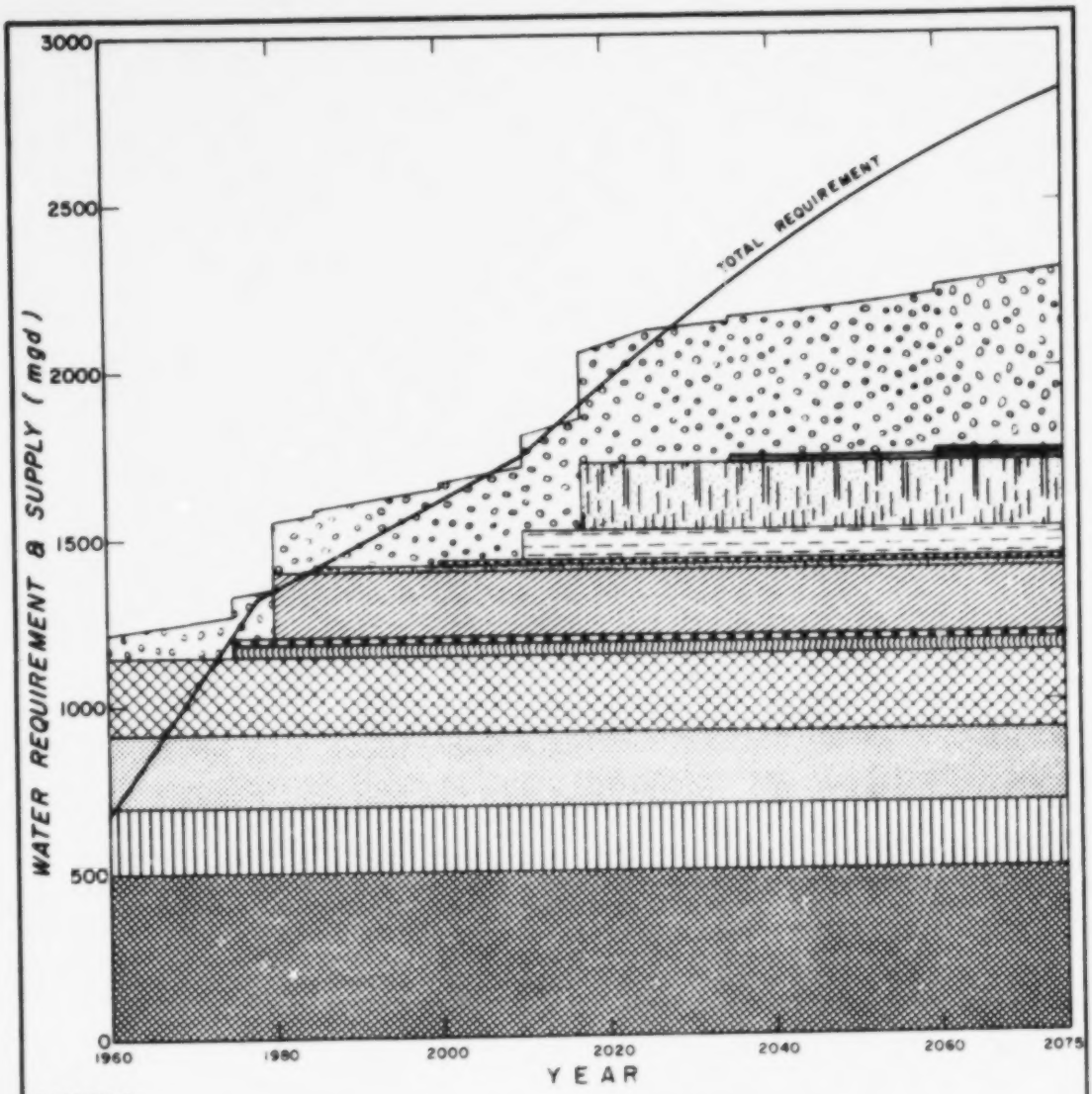
Table IX-1

Future Water Resources of the Lower Brazos River Basin

	Dependable Yield (mgd)
Surface:	
Existing reservoirs and reservoirs under construction	
Whitney	237.5*
Belton	104.7
Waco	54.9
Stillhouse Hollow	63.3
Somerville	36.2
Bistone	3.5
Authorized Reservoirs	
North San Gabriel	19.4
South San Gabriel	11.0
Laneport	22.0
Reservoirs to be completed prior to 2025	
Navasota II and Millican system	307.0
Aquilla Creek	9.7
Walnut Creek	19.4
Allen's Creek	185.7
Use of uncontrolled runoff based on 98 percent low flow conditions	202.5
Reuse of municipal, industrial, and irrigation return flows - varying quantity 1960 - 2025	66.3 - 384.2
Ground Water	450.0
Total resources in 2025	2,111.9
Additional resources available after 2025	
Surface	
Little Brazos River Reservoir	8.7
Wayland Crossing Reservoir	13.6
Reuse of additional municipal, industrial and irrigation return flows - varying quantity 2025 - 2075 (gross 384.2 - 545.5)	net 0 - 161.3
Total resources in 2075	2,295.5

*This is the effective yield of Whitney Reservoir as calculated by the Public Health Service which is reduced from the 304.0 mgd areal yield since power releases do not always coincide with downstream needs. The difference of 66.5 mgd is considered lost to the basin and wasted to the Gulf of Mexico.

Source: Corps of Engineers 1/



LEGEND

- EXISTING RESERVOIRS
- UNCONTROLLED RUNOFF
- PRESENT GROUNDWATER DEVELOPMENT
- ADDITIONAL GROUNDWATER DEVELOPMENT
- LANEPORT & N. SAN GABRIEL RESERVOIRS
- AQUILLA CREEK RESERVOIR
- MILLICAN RESERVOIR
- S SAN GABRIEL RESERVOIR
- WALNUT CREEK RESERVOIR
- NAVASOTA NO. 2 RESERVOIR
- ALLENS CREEK RESERVOIR
- WAYLAND CROSSING RESERVOIR
- LITTLE BRAZOS RIVER RESERVOIR
- REUSEABLE RETURN FLOWS

NOTE: DATE OF FIRST USE OF PROPOSED RESERVOIRS WAS DETERMINED BY LOCAL AREA STUDIES.

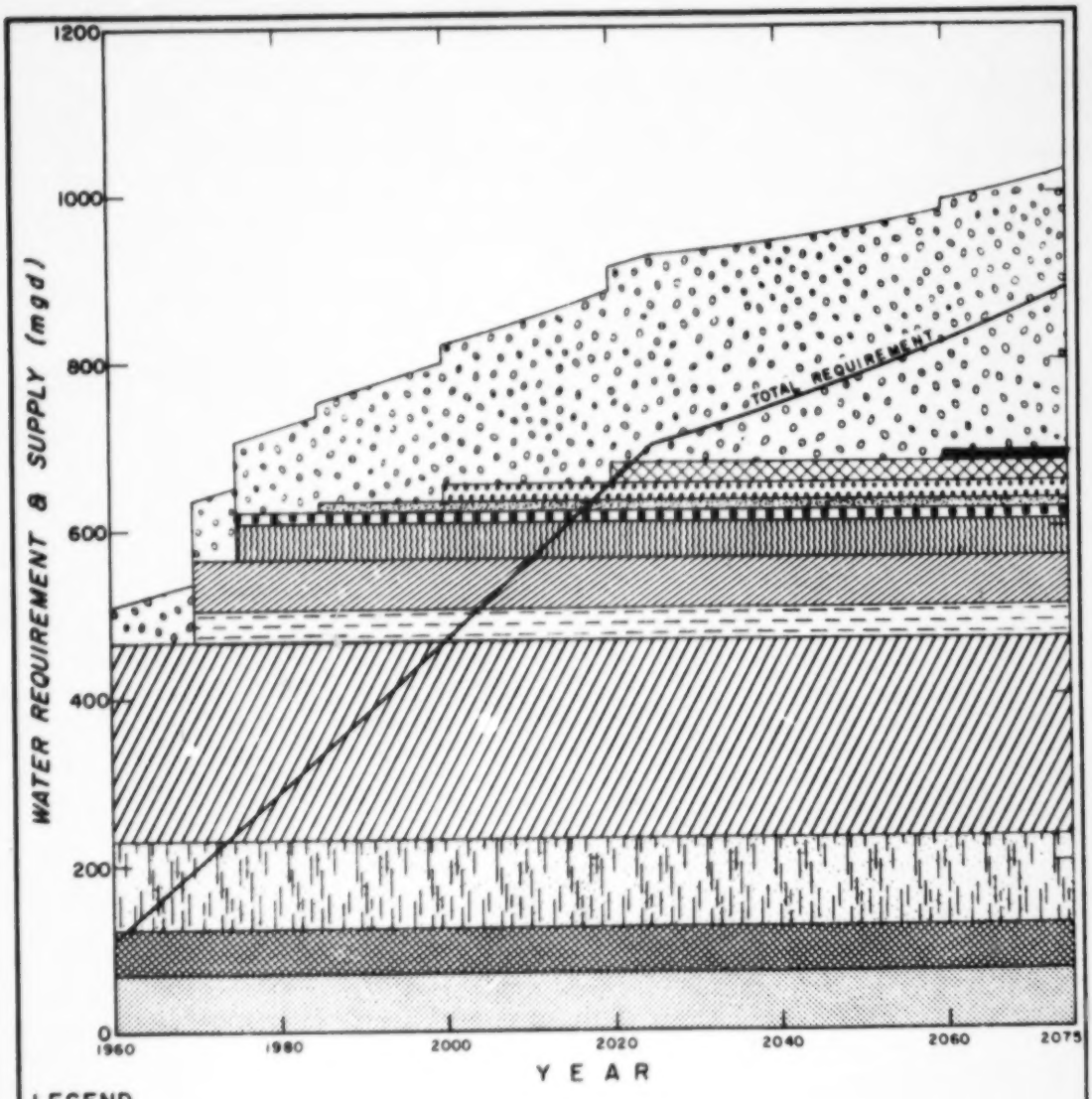
* INCLUDES NAVASOTA RIVER & AQUILLA CREEK WATERSHEDS & INTERVENING COASTAL AREA

WATER SUPPLY & WATER QUALITY CONTROL STUDY
NAVASOTA RIVER WATERSHED
LOWER BRAZOS RIVER SYSTEM, TEXAS

WATER REQUIREMENT AND SUPPLY
(LOWER BRAZOS RIVER BASIN*)

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
Public Health Service
REGION VII DALLAS, TEXAS

FIGURE IX-1



LEGEND

- PRESENT GROUNDWATER DEVELOPMENT
- WACO RESERVOIR
- BELTON RESERVOIR
- WHITNEY RESERVOIR
- SOMERVILLE RESERVOIR
- STILLHOUSE HOLLOW RESERVOIR
- LANEPORT & N. SAN GABRIEL RESERVOIRS
- AQUILLA CREEK RESERVOIR
- S. SAN GABRIEL RESERVOIR
- WALNUT CREEK RESERVOIR
- ADDITIONAL GROUNDWATER DEV.
- LITTLE BRAZOS RIVER RES.
- REUSEABLE RETURN FLOWS

NOTE: DATE OF FIRST USE OF PROPOSED RESERVOIRS WAS DETERMINED BY LOCAL AREA STUDIES.

* DOES NOT INCLUDE NAVASOTA RIVER WATERSHED.

WATER SUPPLY & WATER QUALITY CONTROL STUDY
NAVASOTA RIVER WATERSHED
LOWER BRAZOS RIVER SYSTEM, TEXAS

WATER REQUIREMENT AND SUPPLY

(LOWER BRAZOS ABOVE NAVASOTA RIVER*)

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
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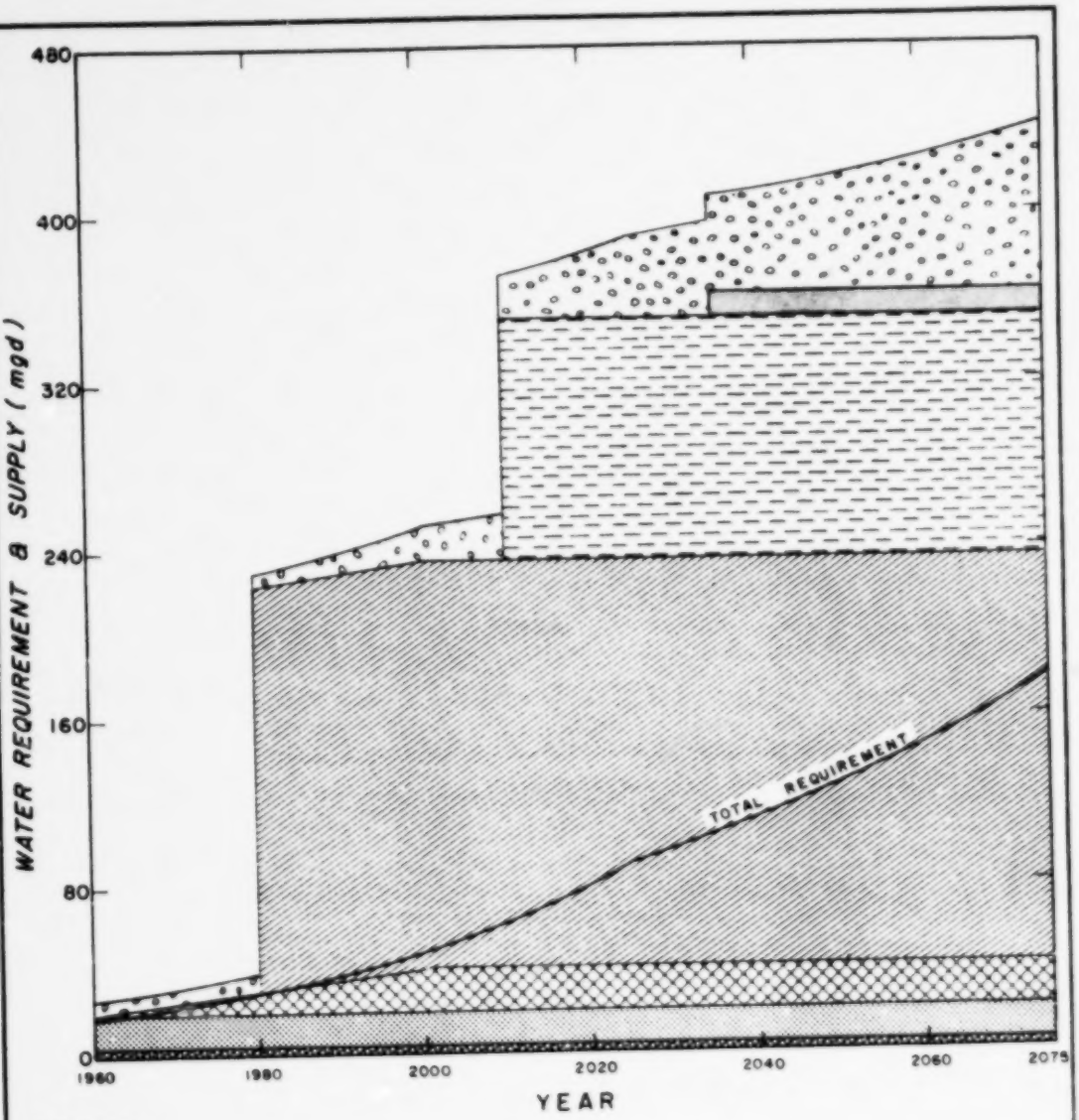
FIGURE IX-2



LEGEND

- BISTONE RESERVOIR
- PRESENT GROUNDWATER DEVELOPMENT
- ADDITIONAL GROUNDWATER DEVELOPMENT
- MILLICAN RESERVOIR
- NAVASOTA NO. 2 RESERVOIR
- WAYLAND CROSSING RESERVOIR
- REUSEABLE RETURN FLOWS

NOTE: DATE OF FIRST USE OF PROPOSED RESERVOIRS WAS DETERMINED BY LOCAL AREA STUDIES.

WATER SUPPLY & WATER QUALITY CONTROL STUDY
NAVASOTA RIVER WATERSHED
LOWER BRAZOS RIVER SYSTEM, TEXAS

WATER REQUIREMENT AND SUPPLY

(NAVASOTA RIVER WATERSHED ONLY)

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
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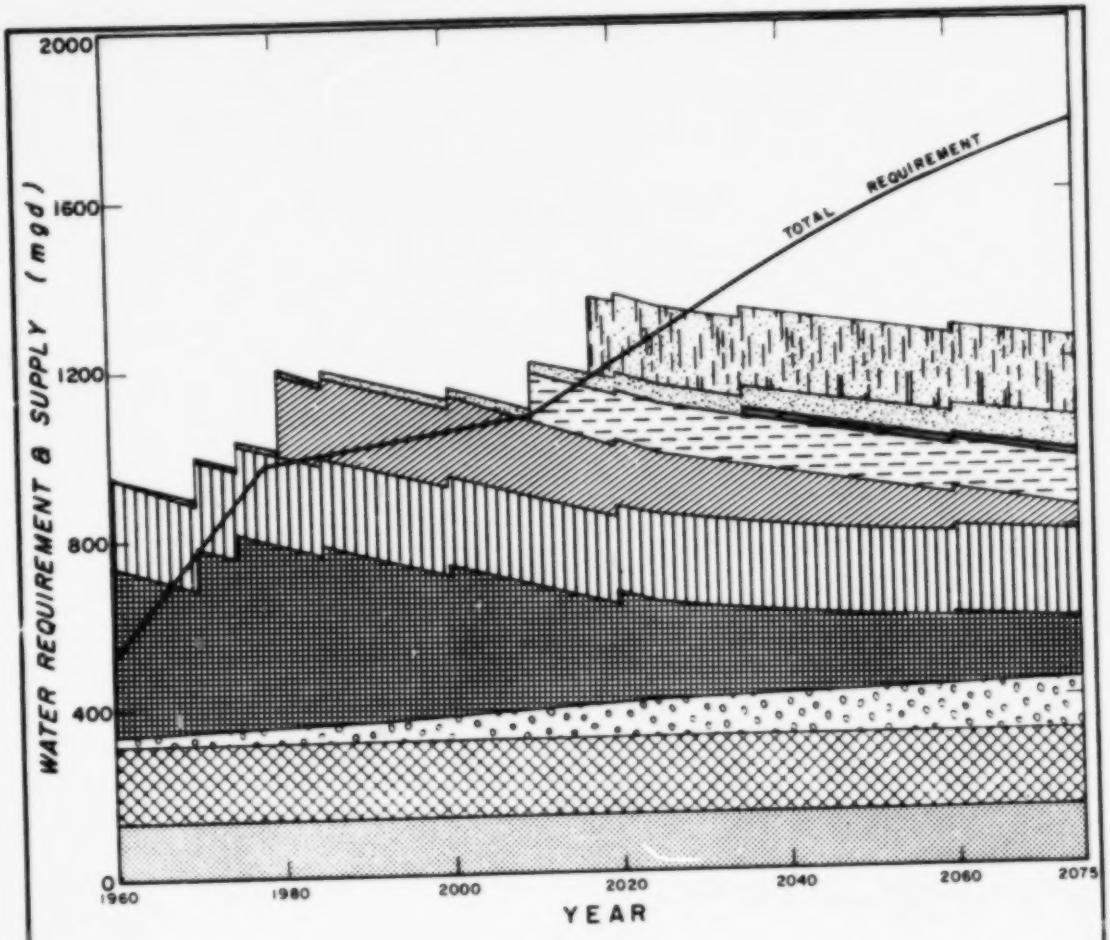
FIGURE IX—3



LEGEND

- PRESENT GROUNDWATER DEVELOPMENT
- ADDITIONAL GROUNDWATER DEVELOPMENT
- REUSEABLE RETURN FLOWS
- SURPLUS WATERS FROM BRAZOS RIVER ABOVE CONFLUENCE OF NAVASOTA RIVER
- UNCONTROLLED RUNOFF AVAILABLE (98% LOW FLOW CONDITIONS)
- SURPLUS WATER FROM MILLICAN RESERVOIR
- NAVASOTA NO. 2 RESERVOIR
- WAYLAND CROSSING RESERVOIR
- RETURN FLOWS FROM NAVASOTA RIVER WATERSHED
- ALLENS CREEK RESERVOIR

NOTE: DATE OF FIRST USE OF PROPOSED RESERVOIRS WAS DETERMINED BY LOCAL AREA STUDIES

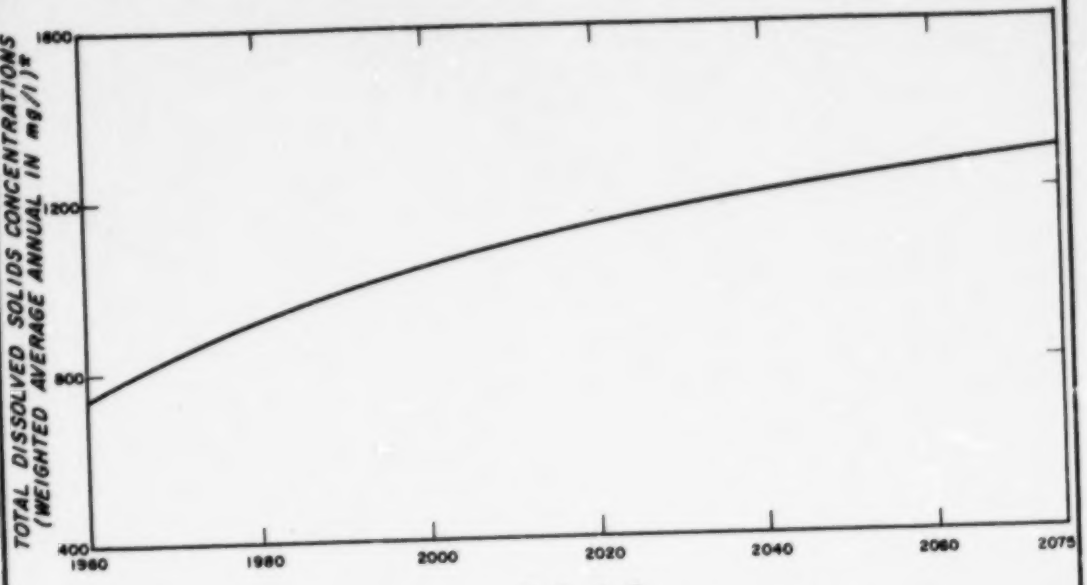
*INCLUDES INTERVENING COASTAL AREA

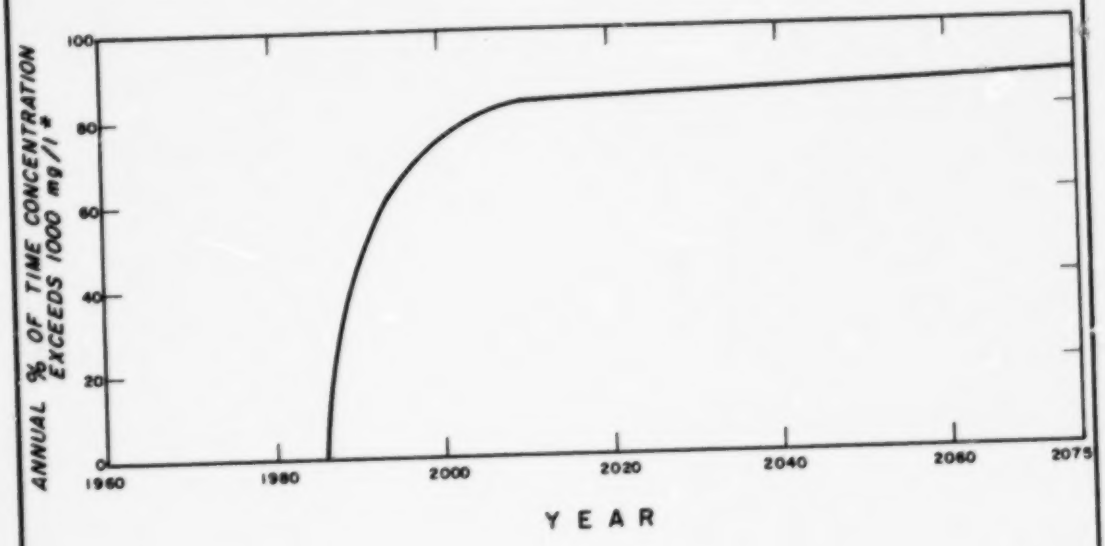
WATER SUPPLY & WATER QUALITY CONTROL STUDY
NAVASOTA RIVER WATERSHED
LOWER BRAZOS RIVER SYSTEM, TEXAS

WATER REQUIREMENT AND SUPPLY
(LOWER BRAZOS BELOW NAVASOTA RIVER*)

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
Public Health Service
REGION VII DALLAS, TEXAS

FIGURE IX-4





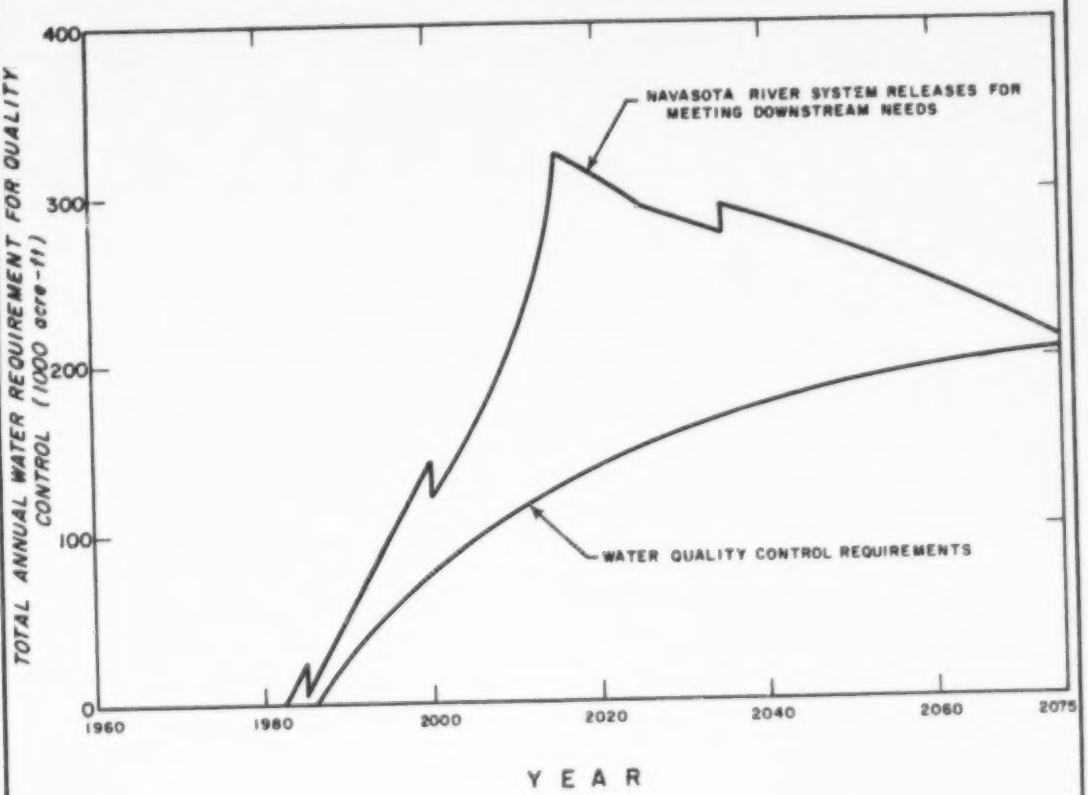
* BASED ON MONTHLY VALUES

WATER SUPPLY & WATER QUALITY CONTROL STUDY
NAVASOTA RIVER WATERSHED
LOWER BRAZOS RIVER SYSTEM, TEXAS

WATER QUALITY CONTROL PLAN
(PART I)

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
Public Health Service
REGION VII DALLAS, TEXAS

FIGURE IX-5



WATER SUPPLY & WATER QUALITY CONTROL STUDY
NAVASOTA RIVER WATERSHED
LOWER BRAZOS RIVER SYSTEM, TEXAS

WATER QUALITY CONTROL PLAN
(PART 2)

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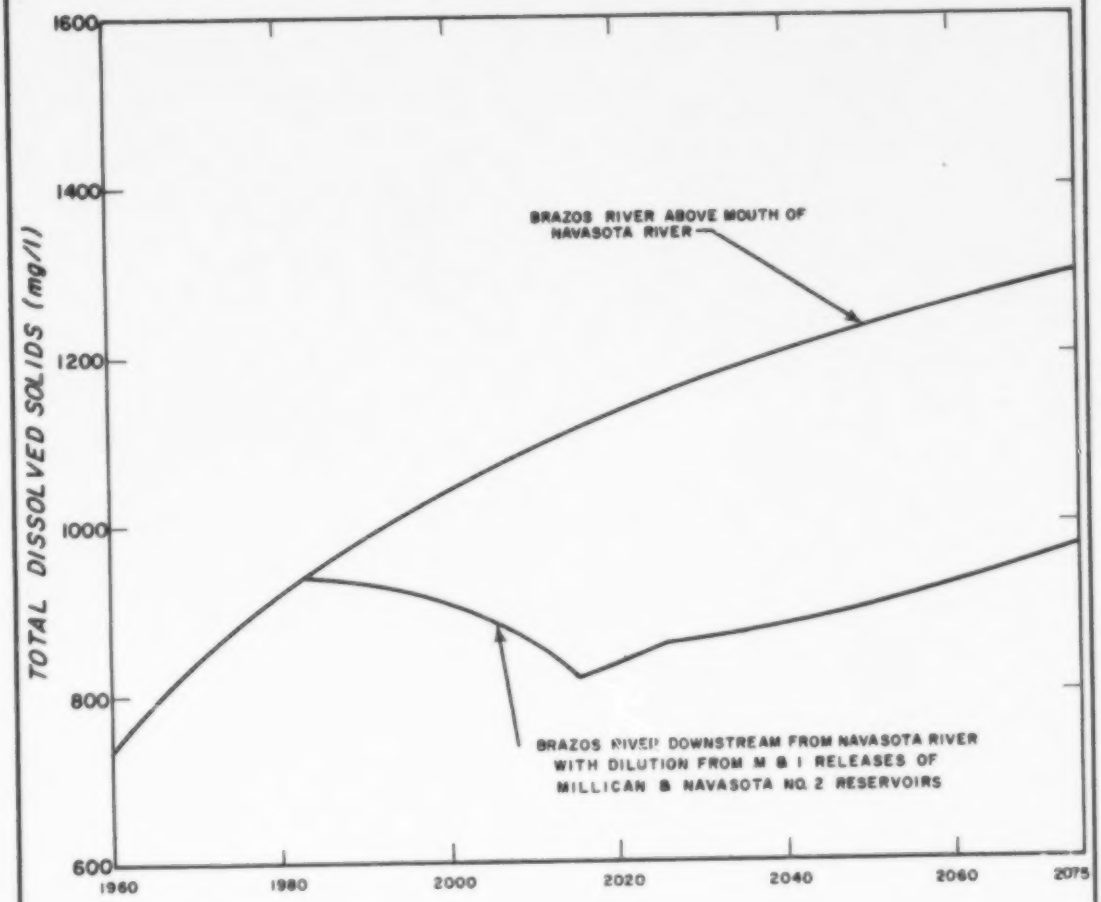
FIGURE IX-6



WATER SUPPLY & WATER QUALITY CONTROL STUDY
NAVASOTA RIVER WATERSHED
LOWER BRAZOS RIVER SYSTEM, TEXAS

WATER QUALITY CONTROL PLAN
(PART 3)

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
Public Health Service
REGION VII DALLAS, TEXAS

FIGURE IX—7

shown in figure IX-5. Also shown is the annual percent of time (based on a monthly analysis) that the concentration will exceed 1,000 mg/l.

A total annual requirement curve for diluting these waters sufficiently to maintain concentrations below 1,000 mg/l with water from the Navasota River system is shown in figure IX-6. Included on the same figure is a curve showing Navasota River system releases for meeting downstream municipal and industrial water supply needs. From these curves it is concluded that there is no need for storage of water for quality control purposes during the study period.

Figure IX-7 shows the expected total dissolved solids concentration under 98 percent low flow condition in the Brazos River downstream from the Navasota River with the municipal and industrial releases from the Navasota River system. This curve shows that after the system is placed into operation, the total dissolved solids concentration will vary from 818 mg/l in the year 2015 to 976 mg/l in the year 2075. The reduction in total dissolved solids concentrations achieved by these releases is not considered sufficient to create significant benefits to water users in the lower Brazos basin.

If current studies of the upper Brazos River show that containment of the natural mineral pollution load is feasible, the mineral quality of the waters of the lower Brazos River will be greatly improved.

Project Construction Sequence

The sequence of construction for the proposed Federal reservoir developments was determined from local area requirement and supply studies. There is a need in the Navasota River basin for the first stage of Millican - Navasota II Reservoir system in the year 1980. (See figure IX-3.) The second stage, Navasota II Reservoir, is needed to meet needs of the Brazos basin and coastal area below the Navasota River in the year 2010. (See figure IX-4.)

Present practice in the southwest is to plan construction about 10 years ahead of actual needs. On this basis, the benefits for Millican Reservoir need not be discounted, while the discount period for the Navasota II Reservoir will be 25 years, using the year 1975 as "present" for purposes of benefit calculations.

Alternatives

After consideration of several other reservoir sites as well as ground water development, it is concluded that the most reasonable alternative to the multiple-purpose two-stage development in the Navasota River basin is a single-purpose two-stage development at the same locations.

X. BENEFITS

Method of Evaluation

Senate Document No. 97 (87th Congress, 2nd session) makes the following statement concerning evaluation of benefits of municipal and industrial water supply storage in Federal reservoirs:

> "The amount water users should be willing to pay for such improvements in lieu of foregoing them affords an appropriate measure of this value. In practice, however, the measure of the benefit will be approximated by the cost of achieving the same results by the most likely alternative means that would be utilized in the absence of the project."

This alternative cost method was used to evaluate storage requirements for municipal and industrial use in the multiple-purpose reservoir projects proposed to be developed in the Navasota River basin. The values determined in this way are considered to be minimum annual benefits.

Costs

For purposes of comparison of alternatives, capital costs were converted to equivalent annual costs and added to the estimated annual operation and maintenance costs. The costs were determined for the date of first use of the project and, when necessary, discounted to "present" 1975 values.

Water Supply Benefits

A summary of the annual project benefits is shown in table X-1. The methods of calculation used for the benefit evaluation are shown in Appendix B. Values shown represent present worth in 1975. Since Navasota II Reservoir is not needed until the year 2010, the benefit was discounted 25 years.

Table X-1

Summary of Project Water Supply Benefits

Reservoir	Yield (mgd)	Benefits	
		Annual (1975 $)	Equivalent Cents per 1,000 gal.
Millican	193.8	$1,418,000	2.0
Navasota II	113.1	$ 914,000	2.2

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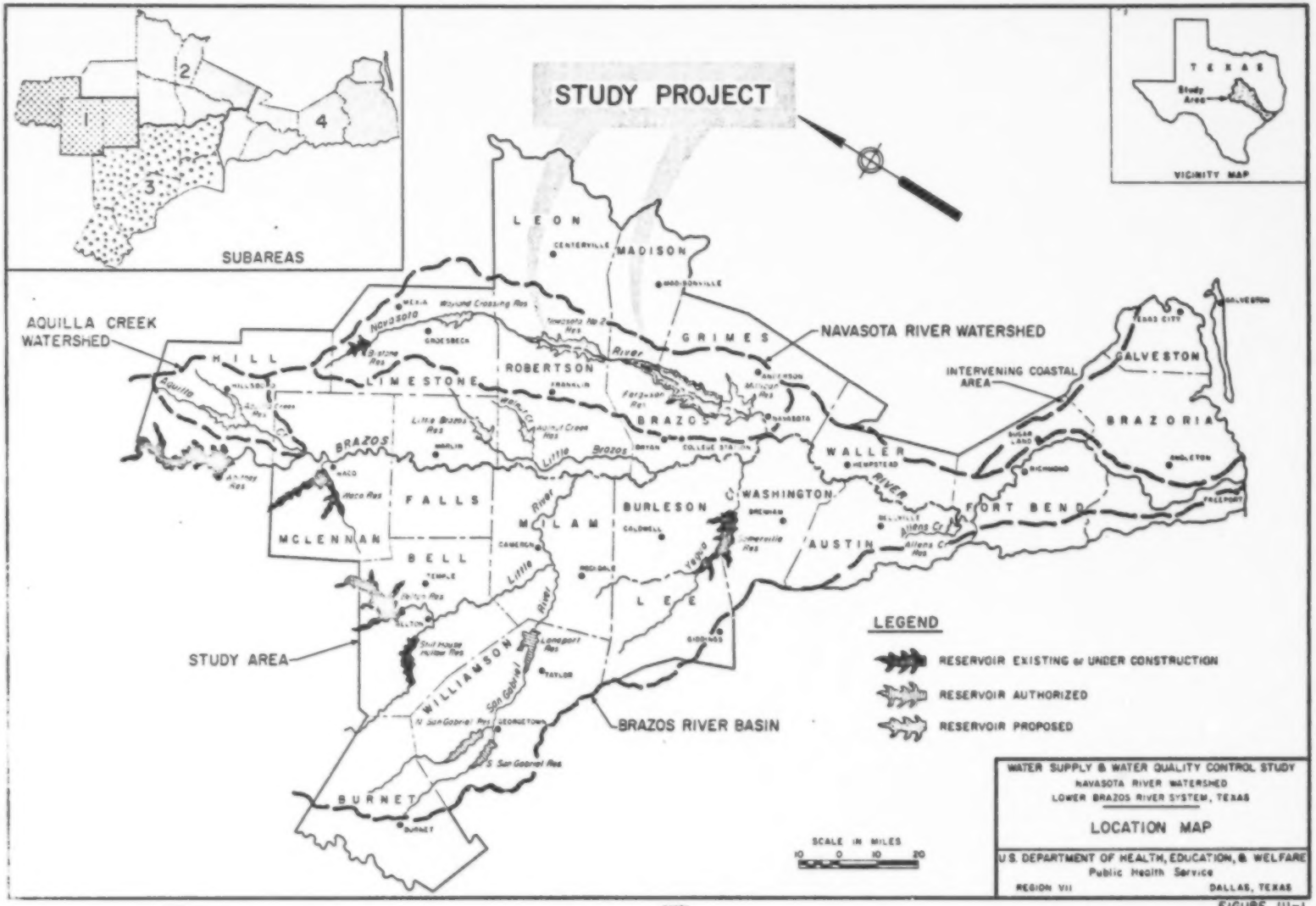
STUDY PROJECT
SUBAREAS
1
2
3
4
TEXAS
Study Area
VICINITY MAP
AQUILLA CREEK WATERSHED
NAVASOTA RIVER WATERSHED
INTERVENING COASTAL AREA
STUDY AREA
BRAZOS RIVER BASIN
LEON
MADISON
GRIMES
HILL
LIMESTONE
ROBERTSON
BRAZOS
FALLS
MCLENNAN
BELL
MILAM
BURLESON
WASHINGTON
WALLER
AUSTIN
FORT BEND
GALVESTON
BRAZORIA
LEE
WILLIAMSON
BURNET
LEGEND
RESERVOIR EXISTING or UNDER CONSTRUCTION
RESERVOIR AUTHORIZED
RESERVOIR PROPOSED
SCALE IN MILES
10 0 10 20
WATER SUPPLY & WATER QUALITY CONTROL STUDY
NAVASOTA RIVER WATERSHED
LOWER BRAZOS RIVER SYSTEM, TEXAS
LOCATION MAP
U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
Public Health Service
REGION VII
DALLAS, TEXAS

FIGURE III-1

APPENDIX A

Present and Projected Study Area
Municipal and Industrial Return Flows and Waste Loads

Subarea and County	1962* Return Flow (mgd)	1962* P.E. (BOD) Discharged	1962* Total Dissolved Solids Discharged (tons/day)	2025 Return Flow (mgd)	2025 P.E. (BOD) Discharged	2025 Total Dissolved Solids Discharged (tons/day)	2075 Return Flow (mgd)	2075 P.E. (BOD) Discharged	2075 Total Dissolved Solids Discharged (tons/day)
Subarea 1									
Falls	0.58	3,510	0.99	3.27	4,368	5.56	7.50	9,804	12.53
Hill	0.79	1,370	1.10	3.35	4,620	4.65	7.14	9,144	10.39
McLennan	11.54	16,150	15.44	52.43	70,248	71.05	87.04	112,968	111.98
Subtotal	12.91	21,030	17.53	59.05	79,236	81.26	101.68	131,916	134.90
Subarea 2									
Brazos	2.66	1,590	7.98	32.97	46,908	98.81	66.55	88,080	201.34
Grimes	0.18	730	0.43	1.83	2,244	4.33	3.75	3,624	8.78
Leon	0.17	400	0.35	7.32	5,076	14.96	15.13	9,828	30.72
Limestone	0.59	2,360	1.17	3.52	3,912	7.00	7.46	7,836	14.45
Madison	0.15	440	0.46	3.09	2,676	9.42	7.64	5,268	19.56
Robertson	0.56	385	1.28	7.11	5,232	16.26	15.63	11,832	37.36
Subtotal	4.31	5,905	11.67	55.84	66,048	150.78	116.16	126,468	312.21
Subarea 3									
Bell	8.56	7,515	11.38	15.55	21,624	20.63	22.16	28,236	28.75
Burleson	0.19	940	0.41	2.49	2,100	5.33	13.01	9,456	27.16
Burnet	0.23	100	0.45	1.42	1,860	2.80	2.45	3,072	4.95
Lee	0.21	200	0.50	0.41	972	0.98	0.83	1,800	1.94
Milam	0.42	730	1.01	8.19	10,308	19.77	12.75	15,288	32.59
Williamson	1.21	440	2.78	2.57	5,820	5.91	5.64	11,556	13.47
Subtotal	10.82	9,925	16.53	30.63	42,684	55.42	56.84	69,408	108.86
Subarea 4									
Austin	0.22	200	0.82	2.14	3,288	8.01	3.99	5,784	17.75
Brazoria	4.10	4,110	6.15	161.30	291,564	242.41	328.86	587,976	501.41
Fort Bend	1.39	5,180	5.06	23.93	36,948	87.14	54.28	79,524	203.00
Galveston	11.35	8,340	18.97	248.28	429,444	414.90	540.60	918,312	928.41
Waller	0.26	30	0.87	2.02	3,108	6.73	3.05	4,440	10.02
Washington	0.50	50	1.32	2.36	3,396	6.23	4.35	5,736	12.71
Subtotal	17.82	17,910	33.19	440.03	767,748	765.42	935.13	1,601,772	1,673.30
TOTAL	45.86	54,770	78.92	585.55	955,716	1,052.88	1,209.81	1,929,564	2,229.27

*Source: Texas State Department of Health 8/, and Public Health Service 10/

APPENDIX B

Benefit Calculations

Millican Reservoir Project

Estimated first cost	$34,200,000
Estimated interest during construction	$ 3,206,250
Estimated total investment	$37,406,250

Amortize private investment for 25 years at 4 percent (37,406,250)(0.06401) = $2,394,374 per year.

Convert to equivalent Federal investment to provide for same annual payment.

Present worth of 1 per period at 3 1/8 percent = 17.17308

Then, equivalent Federal investment = (2,394,374)(17.17308) = $41,118,776

Amortize Federal investment for 100 years at 3 1/8 percent

Annual Cost = (41,118,776)(0.03276)	=	$1,347,051
Estimated annual operation and maintenance	=	$ 70,000
Total annual cost	=	$1,417,051
Say		$1,418,000

Therefore, annual value of benefits = $1,418,000

Navasota II Reservoir Project

Estimated first cost	$47,190,000
Estimated interest during construction	$ 5,161,406
Total investment	$52,351,406

Amortize private investment for 25 years at 4 percent (52,351,406)(0.06401) = $3,351,013 per year

Convert to equivalent Federal investment to provide for same annual payment.

Present worth of 1 per period at 3 1/8 percent = 17.17308

Then, equivalent Federal investment = (3,351,013)(17.17308) = $57,547,214

Amortize Federal investment for 100 years at 3 1/8 percent

Annual Cost = (57,547,214)(0.03276) = $1,885,247

Estimated annual operation and maintenance = $ 87,000

Total annual cost = $1,972,247

Discounting the project for 25 years

Present worth of 1 for 25 years at 3 1/8 percent = 0.46334

Annual cost = (1,972,247) (0.46334) = $913,821

Say $914,000

Therefore, annual value of benefits $914,000

APPENDIX C

Effect of Discharge of Treated Sewage on the Quality of Water in Millican Reservoir

General

An investigation has been carried out to determine the effect of the discharge of adequately treated sewage effluent on the water quality in the proposed Millican Reservoir. The cities of Bryan and College Station discharge treated waste to Carter's Creek, a tributary stream of the proposed impoundment. After the reservoir fills, these wastes will flow into a bay formed along Carter's Creek having a width of about 3,000 feet and a length of about 3 miles. This bay will open into the main body of the reservoir approximately 8 miles upstream of the dam.

Effluent Quality

For planning purposes, it was assumed that the effluent from both of the present treatment plants and any proposed plants would comply with State design criteria concerning maximum permissible concentrations of biochemical oxygen demand (BOD) and suspended solids. It was further assumed that the treated waste effluent would be chlorinated.

Water Quality Objectives

Indicators of water quality consistent with water quality requirements of the various reservoir purposes were chosen for this study. The multiple purposes and the more important water quality indicators are summarized below.

Purpose	Water Quality Indicators
Municipal and industrial water supply	Coliform organisms, hardness, dissolved solids, pH, alkalinity, color, odor, turbidity, algae, temperature.
Fish and wildlife	Dissolved oxygen, pH, dissolved solids, algae, other biological forms, turbidity, toxins.
Recreation	Coliform organisms, floating solids, oil, sludge deposits.

The indicators most likely to be affected by the discharge of treated waste effluent are coliform organisms, dissolved oxygen, turbidity, odor, and algae.

Dynamics of Waste Dispersion in Reservoirs

Much has been written in the sanitary engineering and limnology literature that bears on the dynamics of mixing and dispersion of wastes in receiving waters. Ideally the objective of waste disposal in natural water is to allow it to mix and disperse in the receiving water and to be diluted to the extent that bacterial concentrations are reduced to noninjurious and acceptable levels, deleterious substances are maintained at levels that are not toxic to plant and fishlife and do not upset the general ecological balance which may be established in the assimilating system, and undesirable appearance of the wastes are eliminated. The basic problem in reservoirs, therefore, becomes one of concern with the temporal and spatial conveyance and dispersion of the waste throughout the impoundment.

A mathematical model of the Millican Reservoir system was constructed utilizing formulations and data obtained from similar reservoirs. In general, this model permits calculation of dilution ratios which can be expected at various points in the system taking into account (1) the rate of waste discharge, (2) configuration of the reservoir, (3) mixing currents induced by wind, (4) the ratio of concentration of various substances in the natural water to concentration in the waste, and (5) natural biological self-purification mechanisms in the case of organically degradable substances. These studies were made for waste discharge rates varying from the present 2.8 mgd, to the projected 2075 discharge of 50 mgd. Calculations were also made for the intermediate years of 1975 and 2025.

Results

The above calculations showed that dilution ratios ranging from 6:1 to 23:1 can be expected as the wastes move through the reservoir. Profiles showing expected concentrations of the various waste constituents at the selected discharge rates were plotted.

An overplot of threshold concentrations indicated that all of the waste constituents investigated would be reduced to safe levels by naturally occurring dilution. The following comments apply to each of the pollution indicators investigated.

Coliform Organisms - Chlorination of the waste treatment plant effluent coupled with the natural death rate of the coliform indicator organisms and the dilution factors are expected to maintain bacterial concentrations within the accepted limits for body contact water sports even in most of the length of the bay formed along Carter's Creek.

Bacterial concentrations detrimental to water supply are not expected, since any water supply intake would certainly not be located in the vicinity of the waste discharge area.

Dissolved Oxygen - The dissolved oxygen concentrations necessary for maintenance of fish will not be affected by this waste discharge. Biochemical oxygen demand (BOD) was the indicator used to determine the dissolved oxygen. Assuming that the state recommended design criteria of 20 mg/l, 5 day, 20°C. BOD is satisfied, concentrations in the reservoir will be reduced by dilution and natural self-purification to levels found in natural waters.

Turbidity - Again, maintenance of the recommended state criteria of 20 mg/l of suspended solids is expected to prevent any buildup of this physical characteristic to levels above the accepted drinking water standard.

Odor - Any odor resulting from the treated waste discharge would most probably be related to algae production which is discussed below.

Algae - To indicate algae growth in the reservoir, an analysis of the nutrients was made. Nitrogen and phosphorous levels are expected to remain below the generally accepted threshold concentrations which result in algal blooms.

The discharge of treated waste effluents into reservoirs is a common occurrence. Cases of reservoir pollution have occurred, but most of these have been the result of discharge of improperly treated wastes, or discharge of large quantities of waste into relatively small reservoir pools. Considering the size of the proposed reservoir, the magnitude of the projected waste discharges, the degree of treatment provided by both the cities of Bryan and College Station, and the dilutions expected to occur in the reservoir, no appreciable degradation of water quality in Millican Reservoir is expected to result from this source.